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THESIS

DESIGN AND COMPONENT INTEGRATION OF A T63-A-700 GAS TURBINE ENGINE TEST FACILITY

by

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September 1995

Thesis Advisor: Knox T. Millsaps, Jr.

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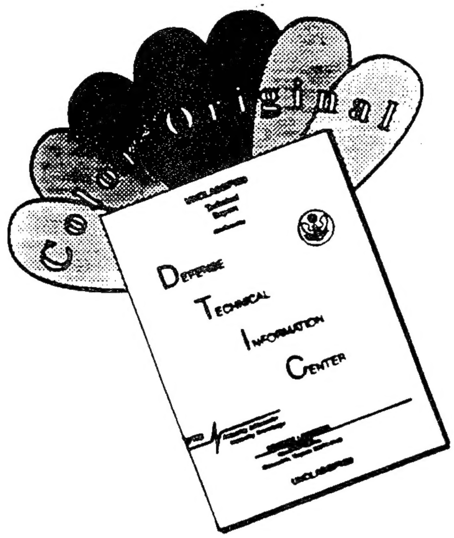

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A gas turbine engine test cell was developed integrating an Allison T63-A-700 helicopter engine with a Superflow water brake dynamometer power absorber. Design specifications were set on all systems and subsystems necessary to operate the engine. Preliminary and detailed designs of the air, water, fuel, and oil systems were developed producing a construction ready overall design. Performance predictions were made which will be compared to experimental data obtained from system operation. Standard Operating Procedures (SOP) and Emergency Operational Procedures (EOP) were developed for engine and auxiliary equipment operation. Preliminary measurements for the structural response of the engine mounting have been made which set engine operating boundaries. The facility has been built and is ready for operation.

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DESIGN AND COMPONENT INTEGRATION OF A T63-A-700 GAS TURBINE ENGINE TEST FACILITY

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ABSTRACT

A gas turbine engine test cell was developed integrating an Allison T63-A-700 helicopter engine with a Superflow water brake dynamometer power absorber. Design specifications were set on all systems and subsystems necessary to operate the engine. Preliminary and detailed designs of the air, water, fuel, and oil systems were developed producing a construction ready overall design. Performance predictions were made which will be compared to experimental data obtained from system operation. Standard Operating Procedures (SOP) and Emergency Operating Procedures (EOP) were developed for engine and auxiliary equipment operation. Preliminary measurements for the structural response of the engine mounting have been made which set engine operating boundaries. The facility has been built and is ready for operation.

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I. INTRODUCTION

Gas turbine engines are the principal means of propulsion and electrical power production used in surface combatant ships. Therefore, it is paramount that all Naval Officers have a good working understanding of the principles of operation and capabilities provided by gas turbine engines. The development of the Gas Turbine Test Facility as part of the Marine Propulsion Laboratory will play a key role in educating Naval Officers by providing hands on instruction in engine operations, as well as, component familiarization provided by data collection and engine cycle analysis.

The purpose of this project was to produce a system design and component integration of a T63-A-700 gas turbine engine with a Superflow 901-SF water brake dynamometer and develop a functioning gas turbine test facility. The gas turbine test facility will be used in conjunction with Mechanical Engineering course, ME 3241, a gas turbine and Diesel power plant performance analysis laboratory.

The gas turbine test cell along with a Diesel cell comprise the Marine Propulsion Laboratory in the Mechanical Engineering Building. Although the Diesel test cell and its identical dynamometer will utilize many of the same auxiliary support systems as the gas turbine engine, the auxiliary support systems are designed for compatibility with the generally more demanding and limiting parameters of the gas turbine engine. Therefore, all discussions and calculations of system requirements for the auxiliary support systems and their designs will be conducted with respect to the gas turbine test facility. The following paragraphs are an overview of the subject matter contained in this paper.

Chapter II is a description of the T63-A-700 gas turbine engine. The principles of operation, major components and assemblies which includes the compressor, gas generator turbine and power turbine, engine subsystems, and performance parameters are discussed.

Chapter III contains a description of the Superflow 901-SF dynamometer test system. The principles of operation, major system components, control console configurations and operations, as well as, the engine mounting and shafting modifications are also discussed.

The physical layout of the Marine Propulsion Laboratory is shown in Chapter IV. The auxiliary support equipment, positioned on the auxiliary machinery equipment pad, is listed along with the physical dimensions of the gas turbine test cell.

Chapter V contains a discussion of the design criteria and considerations involved in integrating the generic auxiliary support equipment, provided during construction of the Mechanical Engineering Building with components specifically designed or purchased for use with the T63-A-700 gas turbine engine. Complete system schematics and design parameters are presented. An equipment listing for the water cooling, fuel, air, oil, and electrical support systems is contained in Appendix C.

The purpose of Chapter VI is to conduct a thermodynamic computer simulation of the water cooling system in order to predict system performance. Transient and steady state heat transfer analyses were completed to set time limits for system operation at various power settings. Alternatives to the present configuration, which were found to be insufficient in supporting gas turbine operations in the steady state at full power, are discussed.

Standard operational procedures for engine light off, fuel oil, and water system recirculation, along with normal and emergency shutdown procedures are contained in Chapter VII.

In Chapter VIII, a summary of the overall system design along with its limitations are discussed along with recommendations for future work which will improve system performance and enhance system operation.

II. ENGINE DESCRIPTION

A. PRINCIPLES OF OPERATION

The gas turbine engine is a Model 250-C18 / T63-A-700 (military) turboshaft engine which is manufactured by Allison Division, General Motors Corporation, Indianapolis, Indiana (Figure 2.1). The engine is relatively small, weighing approximately 140 pounds, and is principally used in the U.S. Army OH-58 light observation helicopter. Over 5,000 engines were delivered for service to the U.S. Military and over 25,000 engines in the Series were manufactured for both military and civilian applications making this engine one of the most produced gas turbine engines to date. The design output power of the engine is 317 SHP at 35,000 power turbine RPM, gearing down to 6,000 RPM at the engine output drive spline, with an air flow of 2,600 SCFM at standard conditions. The specific fuel consumption at full power is 0.697 LB/SHP-HR and the compressor pressure ratio is 6.18:1. The maximum turbine inlet temperature at maximum power is 1,380 °F. [Ref. 1: p. 1-2]

Air enters the engine through a seven stage compressor consisting of six axial stages followed by one centrifugal stage. The compressed air is discharged through a scroll type diffuser into two external ducts which direct the air into a single, reverse flow combustion chamber located in the rear of the engine. The air is mixed with fuel sprayed through a single fuel nozzle mounted at the aft end of the combuster where the fuel is ignited by one igniter plug.

The compressor is driven by a direct shaft from an axial two-stage gas generator turbine which also drives an accessories gear train. The accessories gear train provides input power to the lube oil supply and scavenge elements, as well as, the fuel pump and

gas generator fuel control. The engine is a free turbine engine in which there is no mechanical connection between the gas producer turbine and the power turbine. The power turbine is gas coupled to the gas producer turbine by combustion gases. A two-stage helical reduction gear in the power turbine and accessories gear box is used to reduce the power turbine speed from 35,000 RPM to 6,000 RPM at the output drive spline. The various components will now be discussed in some detail.

B. MAJOR COMPONENTS AND ASSEMBLIES

1. Compressor Assembly

The engine utilizes a seven stage compressor consisting of six axial stages followed by one centrifugal stage combining for a compression ratio of 6.18:1 at a speed 51120 RPM which corresponds to an axial air speed of 0.43 Mach and a mass flow rate of 3.3 LBM/SEC. The compressor efficiency at full power is 85% with a temperature increase of 450 °F across the compressor. The compressor assembly (Figure 2.2) consists of a compressor front support, a case assembly with stator vanes, a rotor assembly, a centrifugal impeller, a front diffuser assembly, a rear diffuser assembly, and a diffuser scroll. Air enters the compressor through the front support where struts guide and direct the air into the first stage of the compressor rotor. The diffuser scroll collects the compressor discharge air at a constant velocity and directs it rearward through two tubes into the combustion section.

2. Combustion Section

The combustion section (Figure 2.3) consists of two compressor discharge air tubes, a combustion outer case, and a combustion liner. The outer combustion case, which houses the combustion liner, is attached to the gas producer turbine support through a bolted flange. The combustion liner is supported at the forward end by the gas producer nozzle vane assembly and at the rear by the fuel nozzle. Compressor discharge air is ducted from the diffuser scroll to the combustion outer case by two compressor discharge air tubes. Air enters the combustion liner at the rear through holes in the liner and is mixed with fuel sprayed from a single fuel nozzle. The mixture is then ignited by a single spark igniter installed in the rear of the outer combustion case causing the combustion gases to move forward out of the combustion liner into the power turbine assembly.

During maintenance and cleaning of the fuel nozzle and igniter, the maintenance person must not remove both the igniter and fuel nozzle simultaneously. If the combustion liner is loose, which often occurs after significant gas turbine operation, the combustion liner will fall against the outer case and prevent reinsertion of the igniter and fuel nozzle into the holes. Realignment of the two holes may only be accomplished through disassembly of the combuster, a time consuming operation.

3. Turbine Assembly

A two-stage gas generator turbine, a two-stage power turbine, and a turbine exhaust collector make up the turbine assembly. The turbine assembly is located immediately forward of the combuster as shown in Figure 2.4. The 100% design speeds of the gas generator turbine and the power turbine are 51,120 RPM and 35,000 RPM respectively.

4. Power and Accessories Gearbox

A single, enclosed cast gearbox housing (Figure 2.5) serves as the structural support for the engine and as an enclosure for the main power and accessory drive train. Power is transmitted from the power turbine to the output drive spline through a double helical reduction gear with a reduction ratio of approximately 5.83:1. Included in the accessory drive train is an input shaft for the starter / generator and output gearing to drive the attached fuel pump. The pressure and scavenge oil pumps are also enclosed in the gearbox housing and are driven by the gas generator turbine.

5. Torque Sensor

The first-stage driven and second-stage driving gear are integrally mounted on the torque meter shaft as shown in Figure 2.6. During normal operation, a forward axial thrust is imparted on the torque meter shaft from the helix angles of the helical reduction gears. This axial thrust is transmitted to a counterbalanced oil piston, which utilizes oil from the lubrication system. A change in cylinder pressure, caused by the axial thrust, is provided to an external connection for gauge measurement. The units of torque measurement is therefore measured in PSIG rather than in FT-LB. Shaft torque is also one of the parameters measured by the dynamometer and is displayed in the units of FT-LB. This will be the principal means of measuring and monitoring shaft torque. A more detailed description of the torque sensor is contained in the installation design manual. [Ref. 1: p. 1-6]

C. MAJOR ENGINE SUBSYSTEMS

1. Lubrication System

The lubrication system is a circulating dry-sump system with supply and scavenge elements enclosed in the accessory gearbox as shown in Figures 2.7 and 2.8. An external oil cooler and storage tank provide both storage and cooling of MIL-L-23699 gas turbine lubricating oil. MIL-L-7808 lubricating oil may be used as an alternative however, MIL-L-23699 and MIL-L-7808 should not be mixed. An oil filter, a filter bypass valve, and a pressure regulating valve are installed as a filter package, which is accessible from the top of the engine, in the upper right hand side of the gearbox housing. A check valve is positioned between the filter package and the accessory gearbox. All engine lines, with the exception of the pressure and scavenge lines to the compressor front bearing and bearings in the gas generator and power turbine supports, are internal to the engine. Indicating, probe-type magnetic chip detectors are installed at the bottom of the power and accessory gearbox and at the oil outlet connection. Whenever a metal chip shorts the open circuit in the chip detector, an indicating light will illuminate. This warning light is located in the airframe therefore an indicating light will be installed on the dynamometer stand for monitoring purposes.

2. Fuel System

Diesel Fuel #2 is the fuel type used in this test facility. The fuel is pumped by two gear type pumping elements located in the fuel pump and filter assembly as shown in Figure 2.9. The use of Diesel Fuel #2 vice JP-4, the fuel used in aircraft applications, is

discussed in Chapter V Section B. The pumping elements are arranged in tandem and driven by a common drive shaft. Fuel enters the engine fuel system at the inlet port of the pump and passes through a low pressure, 5 micron filter before entering the gear elements. The gear elements, which are arranged in a parallel configuration, each have the capacity to provide sufficient fuel supply if the other pumping element should fail. Two discharge check valves are installed to prevent reverse flow in the event of failure of either pumping element. A bypass valve is also installed in the fuel pump and filter assembly to allow fuel to bypass the fuel filter if blockage occurs. The bypass fuel is directed through a pressure regulating valve, which maintains bypass flow pressure above the inlet pressure, to the inlet of the gear elements. The fuel discharged from the supply elements is routed to the fuel nozzle by external fuel lines to the rear of the engine. A single-entry, dual-orifice type fuel nozzle is used to spray fuel into the rear of the combustion liner. The fuel nozzle also contains an integral valve for dividing primary and secondary fuel flow and also acts as a fuel shutoff valve to prevent fuel from entering the combuster in low pressure situations and during shutdown.

3. Ignition System

A capacitor discharge ignition exciter, a spark igniter lead, and a shunted-surface gap spark igniter make up the engine ignition system, displayed in Figure 2.10. The ignition system receives its power from two-12 volt DC batteries externally mounted in series which provide a 24 volt DC power supply to the starter / generator and exciter. The spark igniter lead transfers this energy to the spark igniter attached at the rear of the combuster. The spark igniter utilizes this energy to produce a high temperature, high current arc at the spark igniter gap igniting the fuel / air mixture.

4. Control Systems

The engine control systems control engine power output by controlling the gas generator turbine speed. The power turbine fuel governor lever schedules the power requirements demanded by the operator and schedules the gas generator speed to maintain output shaft speed.

a. Temperature Measurement System

The temperature measurement system consists of four chromel-alumel (K-type), single junction thermocouples at the power turbine inlet. The voltages of the four thermocouples are electrically averaged in the assembly and delivered to a terminal block for connection to an indicator. A complete data acquisition system with separate thermocouples will be used in conjunction with the existing system. Instrumentation plans which are being developed prior to full integration of the engine into the test cell, involve disassembly of the combuster and placement of a thermocouple ring within the combuster for extensive temperature measurement. This procedure will lengthen the combuster section approximately 3 inches.

b. Gas Generator Fuel Control System

The gas generator turbine fuel control utilizes a bypass valve, a metering valve, an acceleration bellows, a governing and enrichment bellows, a manually operated cutoff valve, a maximum pressure relief valve, and a lever assembly to control fuel flow. Fuel is discharged from the fuel pump and filter assembly into the fuel control and is

directed to the metering valve. The bypass valve maintains a constant pressure differential across the metering valve and bypasses excess fuel back to the fuel pump and filter assembly through an external line. The metering valve is operated by lever action through the movement of the governor and acceleration bellows. This lever action controls the extent of the flow orifice opening. Gas generator speed is controlled by a set of flyweights that operate the governor lever thereby, regulating air pressure to the governor and acceleration bellows. The governor actuates the metering valve and regulates fuel flow. The flyweight operation is opposed by variable spring loading established by the throttle lever acting on a spring scheduling cam. [Ref. 2: p. 1-13]

c. Power Turbine Governor Control System

The power turbine speed is scheduled by the power turbine governor lever and spring scheduling cam. This action regulates spring load against flyweights similar to the action described above in the gas generator and in turn controls the fuel metering valve in the fuel control governor. The power turbine governor also provides overspeed protection by providing rapid air pressure bleed capability to limit fuel metering valve actuation.

D. GAS TURBINE OPERATIONS

The present laboratory course, ME 3241, utilizes a Boeing 502-A gas turbine engine for performance analysis. During engine testing, the gas generator turbine speed (N_1) is fixed at a predetermined speed, and the power turbine speed (N_2) is varied. Measurements of engine parameters are taken at each power turbine speed and performance curves are developed.

In the OH-58 helicopter, the airframe for which the T63-A-700 engine is designed, the power turbine and output shaft speed are fixed at approximately 35,000 RPM and 6,000 RPM respectively. As the helicopter main rotor trim (blade pitch) is changed, the power turbine governor provides input to the gas generator fuel control scheduling fuel to the combuster and thereby, changing gas generator turbine speed. In other words, N_1 is highly variable with rotor blade loading while N_2 is fixed.

In order to utilize the T63-A-700 gas turbine engine in the ME 3241 course and conduct the engine performance evaluation in a similar manner as with the Boeing engine, an instrumentation plan is being developed in conjunction with Allison Gas Turbine [Ref. 3] to alter the power turbine governor input to the gas generator fuel control. This modification will allow the gas generator speed to remain fixed while varying output shaft speed and in turn the power turbine speed. Gas generator (N1) and power turbine (N2) speeds will be monitored at the dyno console using the existing tachometer gearing and custom-made magnetic tachometers and meters manufactured by Turbomotive, Inc. [Ref. 4]

E. LEADING PARTICULARS AND PERFORMANCE RATINGS

The leading particulars for the T63-A-700 engine are listed in Table 1. The performance ratings for the engine at standard sea level static conditions are displayed in Table 2.

Dimensions:	
Length	40.4 IN (1.03 m)
Height	22.5 IN (0.57 m)
Width	19.0 IN (0.48 m)
Engine weight (dry):	
T63-A-700	138.5 LB (62.82 kg)
Maximum oil consumption:	0.05 GAL/HR (0.19 L/HR)
Lubricating oil specifications:	Primary: MIL-L-23699 Alternate: MIL-L-7808
Oil pressure limits:	
97% N_1 speed and above	110-130 (PSIG)
78% to 97% N_1 speed	90-130 (PSIG)
Below 78% N_1 speed	50 (PSIG minimum)
Oil inlet temperature:	
Maximum	225 °F
Desired operating range	140-225 °F
Fuel specifications:	
Primary	MIL-T-5624 (JP-4)
Alternate	JP-5, JP-8, JET-A, JETA-1, Diesel Fuel #2
Design power output:	
Maximum power (zero air speed @ STP)	317 SHP
Ram power rating (275 KTS @STP)	335 SHP
Design speeds:	
Gas producer (N1)	100% (51,120 RPM)
Power turbine (N2)	100% (35,000 RPM)
Power output shaft	100% (6,000 RPM)
Overspeed limits:	
Gas Producer	
Maximum continuous	104% (53,164 RPM)
Maximum overspeed (15 sec max)	105% (53,676 RPM)
Maximum measured gas temperature:	1,380 °F (Power Turbine Inlet Temp.) 1,510 °F (Gas Generator Inlet Temp.)
Maximum output shaft torque:	
Transients (less than 10 seconds)	320 (LB-FT)
Takeoff (less than 5 minutes)	293 (LB-FT)
Maximum continuous	249 (LB-FT)

Table 1. Leading Particulars [Ref. 2: p. 1-22 thru 1-23]

Rating	Shaft Horsepower (HP)	Gas Generator Speed (RPM)	Output Shaft Speed (RPM)	Air Flow (SCFM)	Specific Fuel Consumption (LB/SHP-HR)
100%	317	51,120	6,000	2,600	0.697
90%	243	48,650	6,000	2,150	0.725
75%	203	46,950	6,000	1,685	0.762
Start and Idle	35	32,000	500-6,300		61 LB/HR

Table 2. T63-A-700 Performance Ratings [Ref. 1: p.1-2]

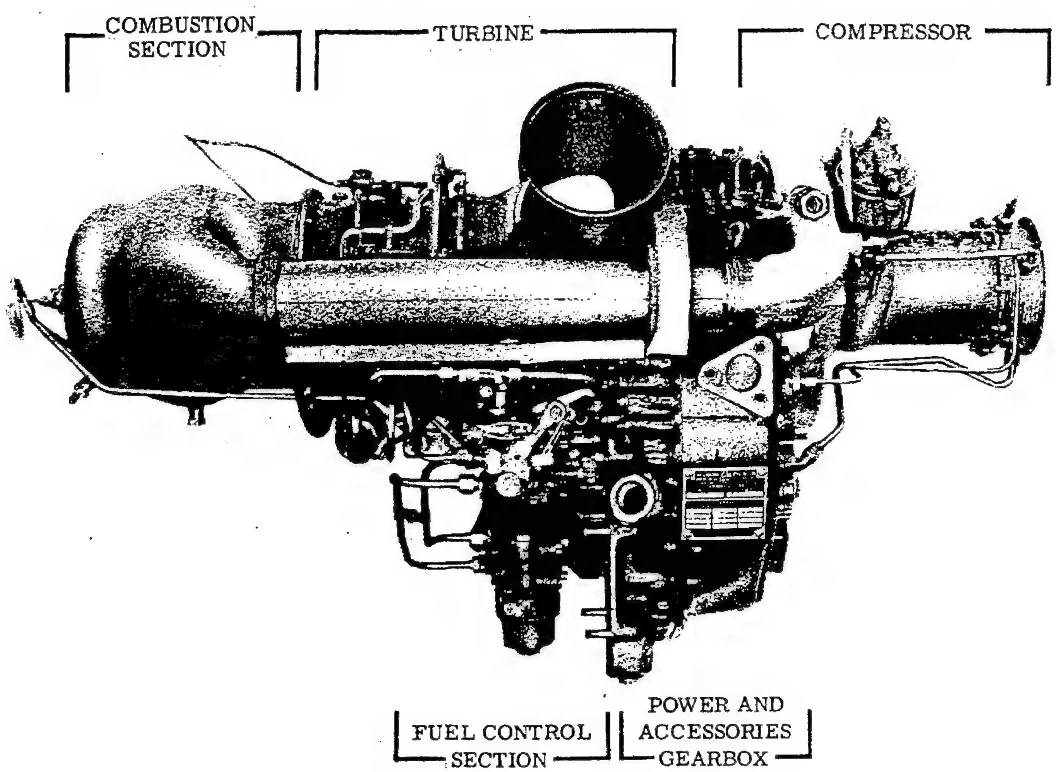


Figure 2.1. T63-A-700 Turboshaft Gas Turbine Engine. "From Ref. [1] with permission from Allison Engine Co."

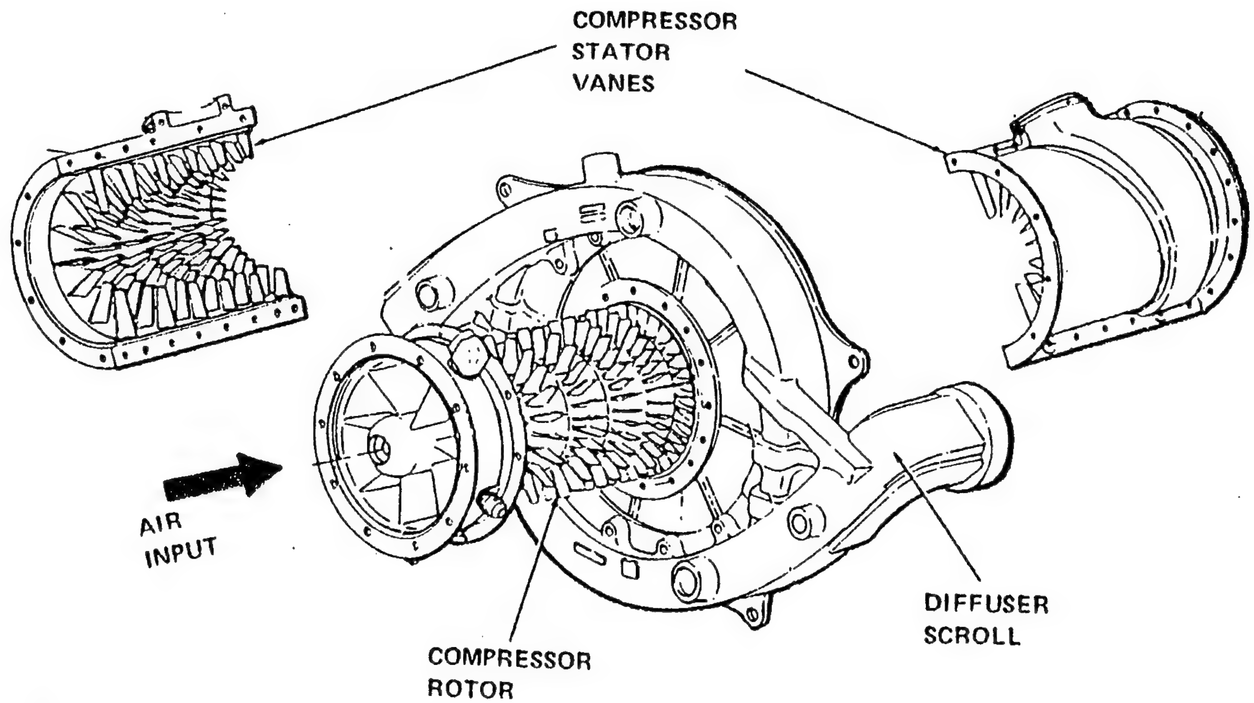


Figure 2.2. T63-A-700 Compressor Assembly.
"From Ref. [2]."

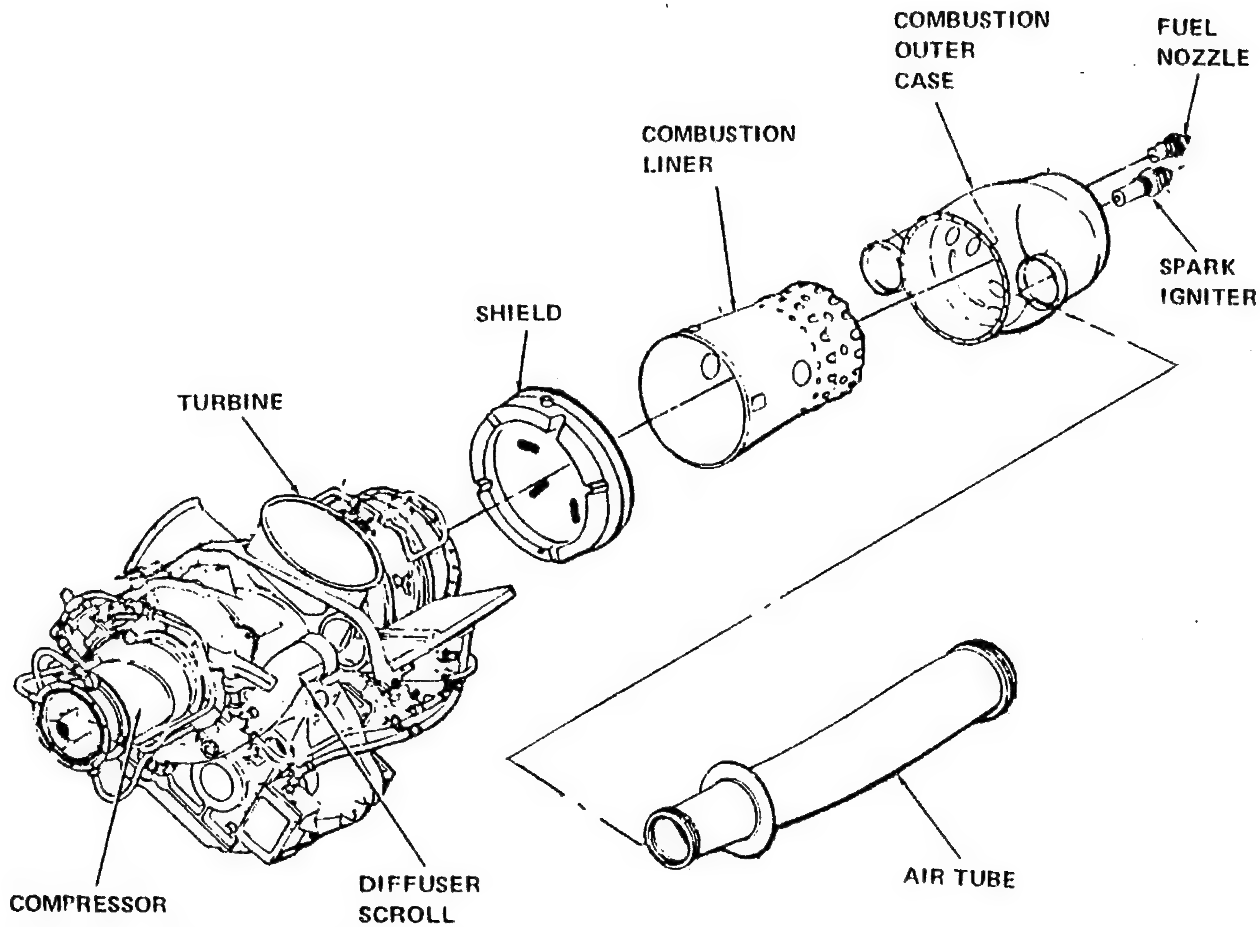


Figure 2.3. T63-A-700 Combuster Assembly.
"From Ref. [2]."

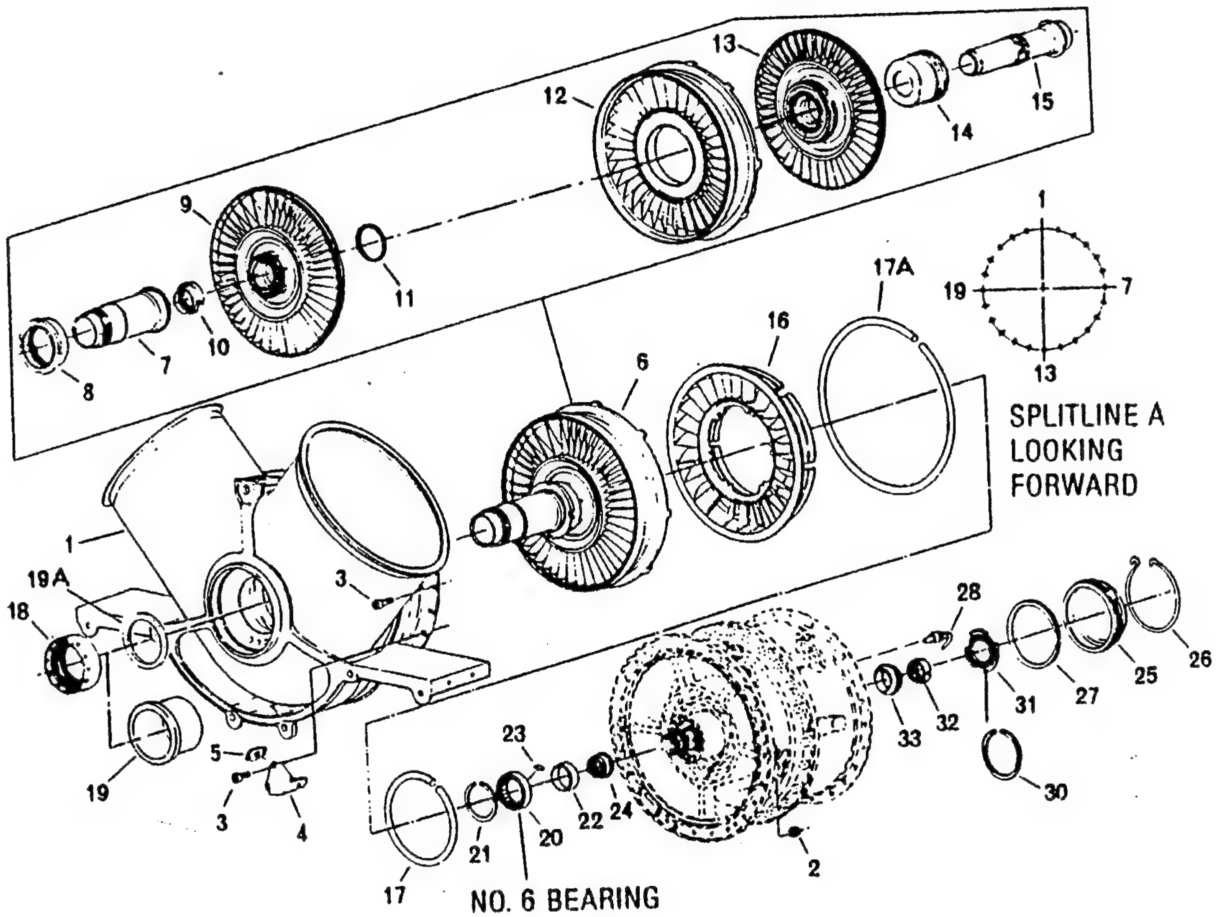


Figure 2.4. T63-A-700 Turbine Assembly.
"From Ref. [2]."

1. Gas Producer Tachometer-Generator
2. Power Takeoff
3. Power Turbine Tachometer Generator
4. Torquemeter Spanner Nut
5. Power Turbine Fuel Governor
6. Spare (not used)
7. Fuel Pump
8. Starter-Generator
9. Power Takeoff
10. Gas Producer Fuel Control

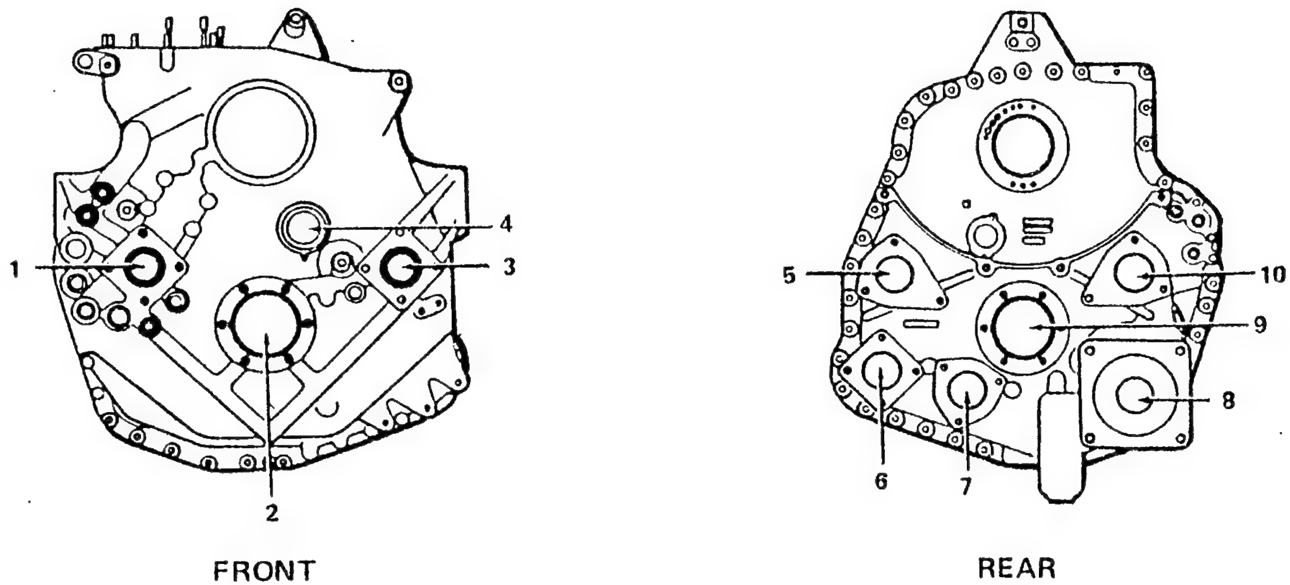


Figure 2.5. T63-A-700 Power and Accessories Gearbox. "From Ref. [2]."

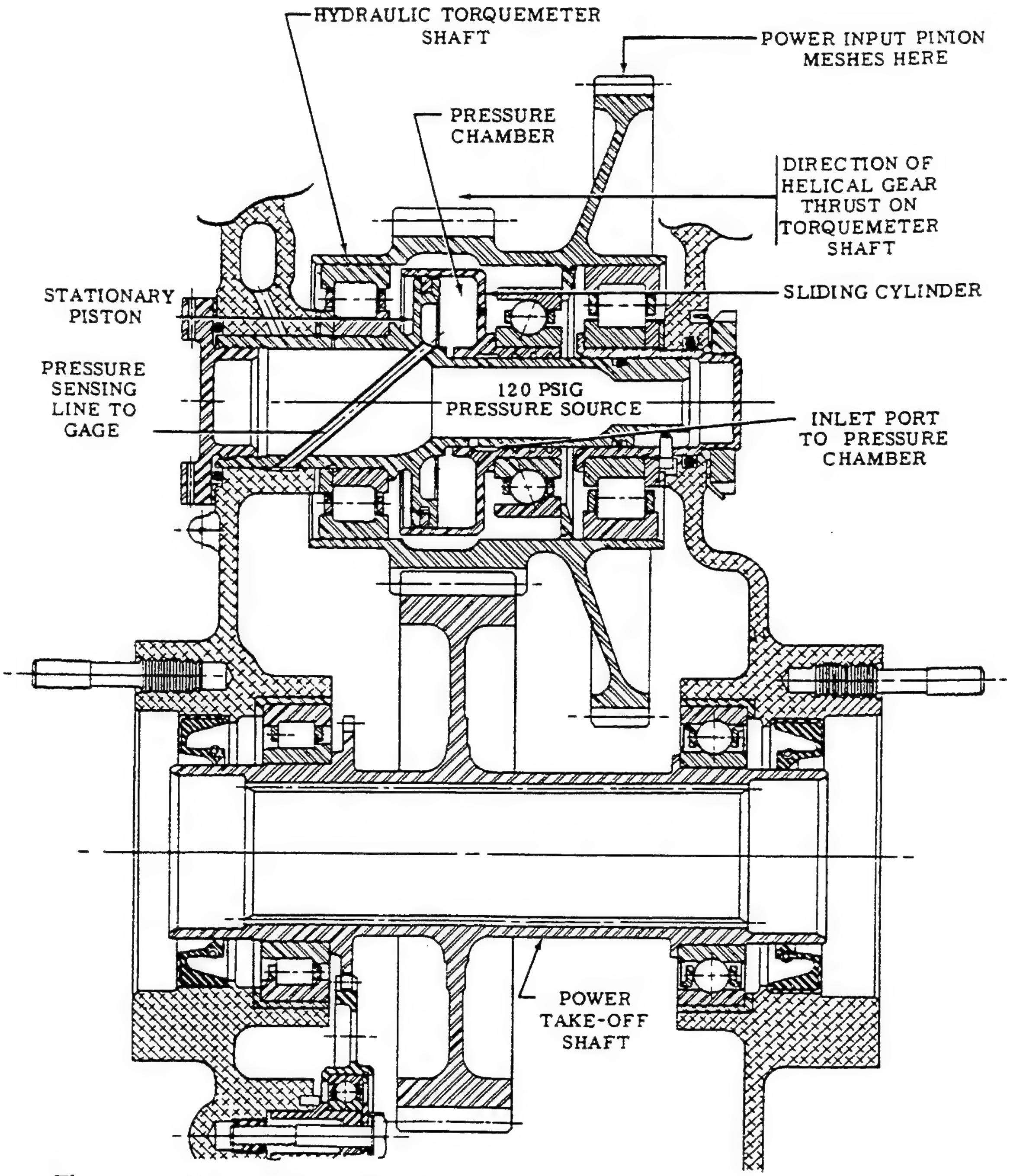


Figure 2.6. T63-A-700 Torque Sensor.
"From Ref. [1] with permission from Allison Engine Co."

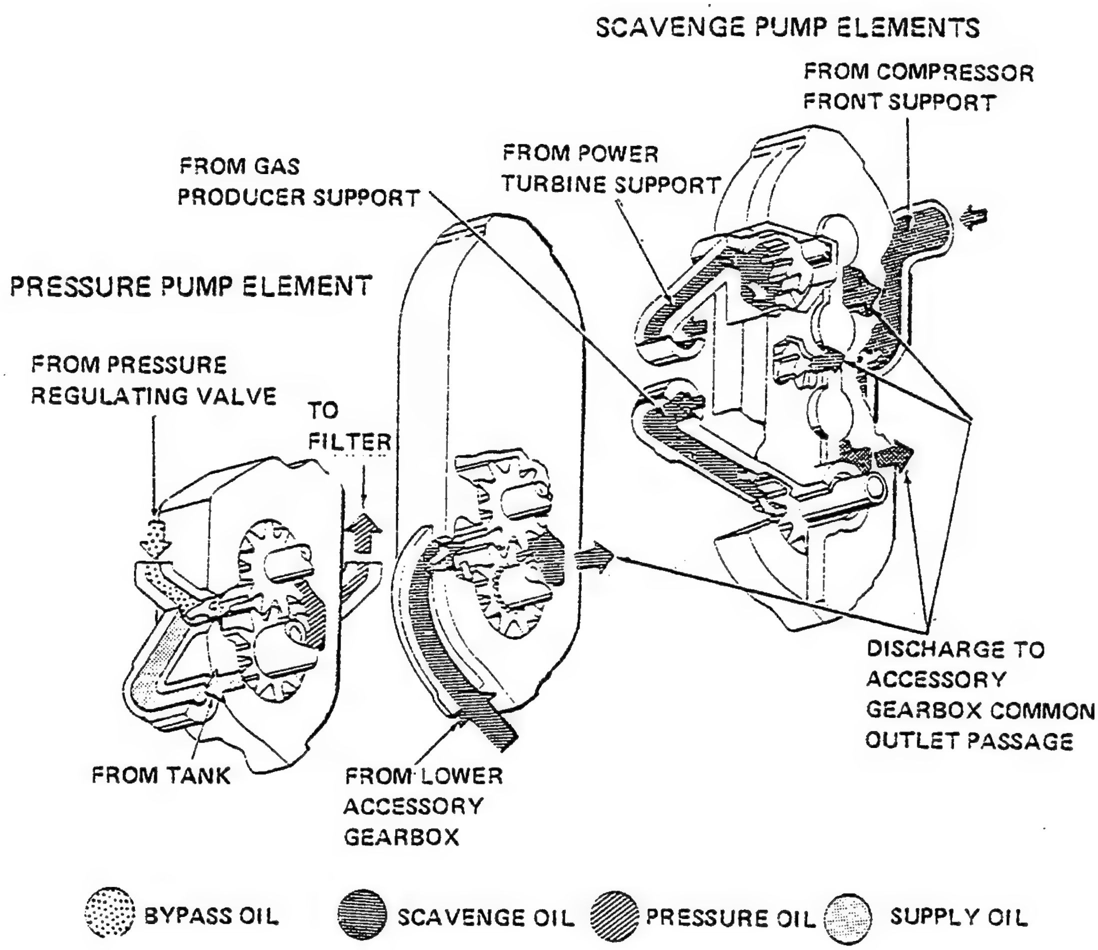


Figure 2.7. T63-A-700 Supply and Scavenge Pump Elements. "From Ref. [2]."

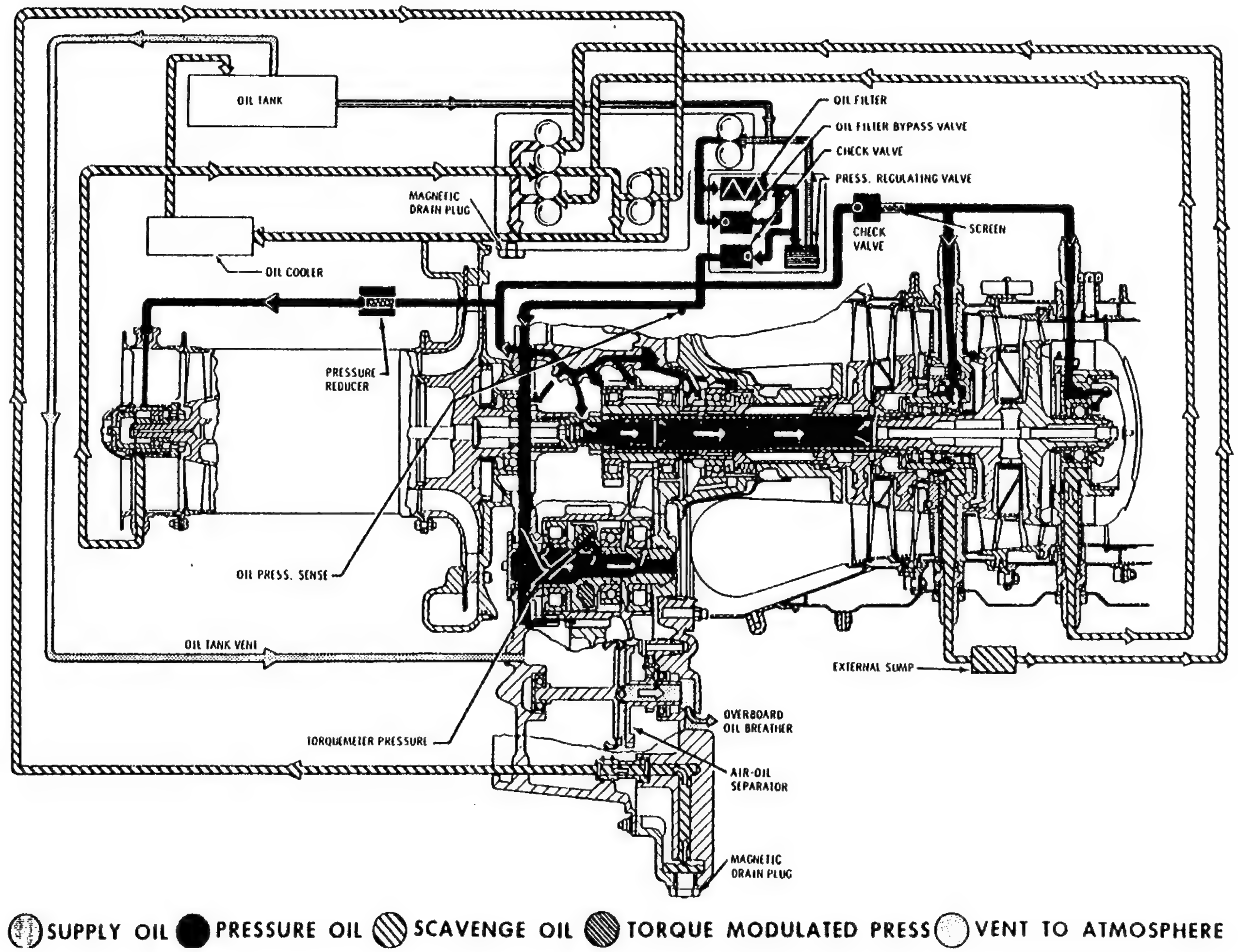


Figure 2.8. T63-A-700 Gas Turbine Engine Lubrication System. "From Ref. [1] with permission from Allison Engine Co."

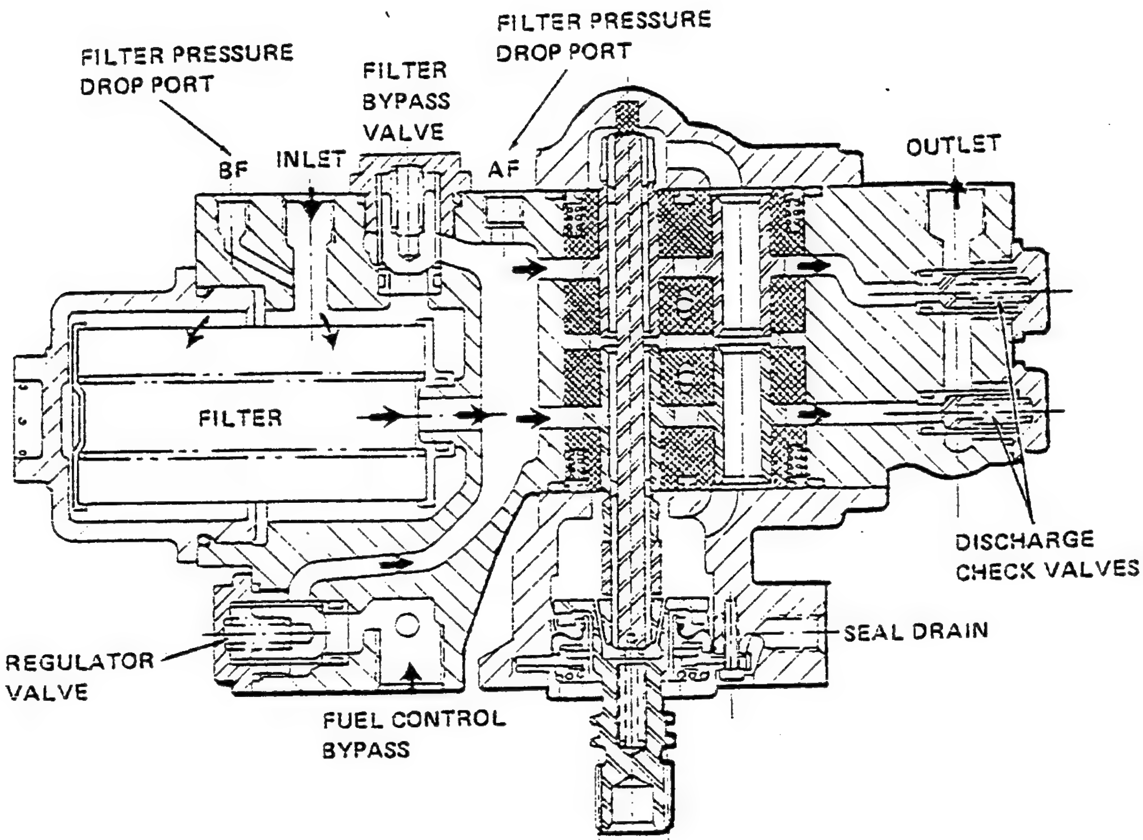


Figure 2.9. T63-A-700 Fuel Pump and Filter Assembly.
"From Ref. [2]."

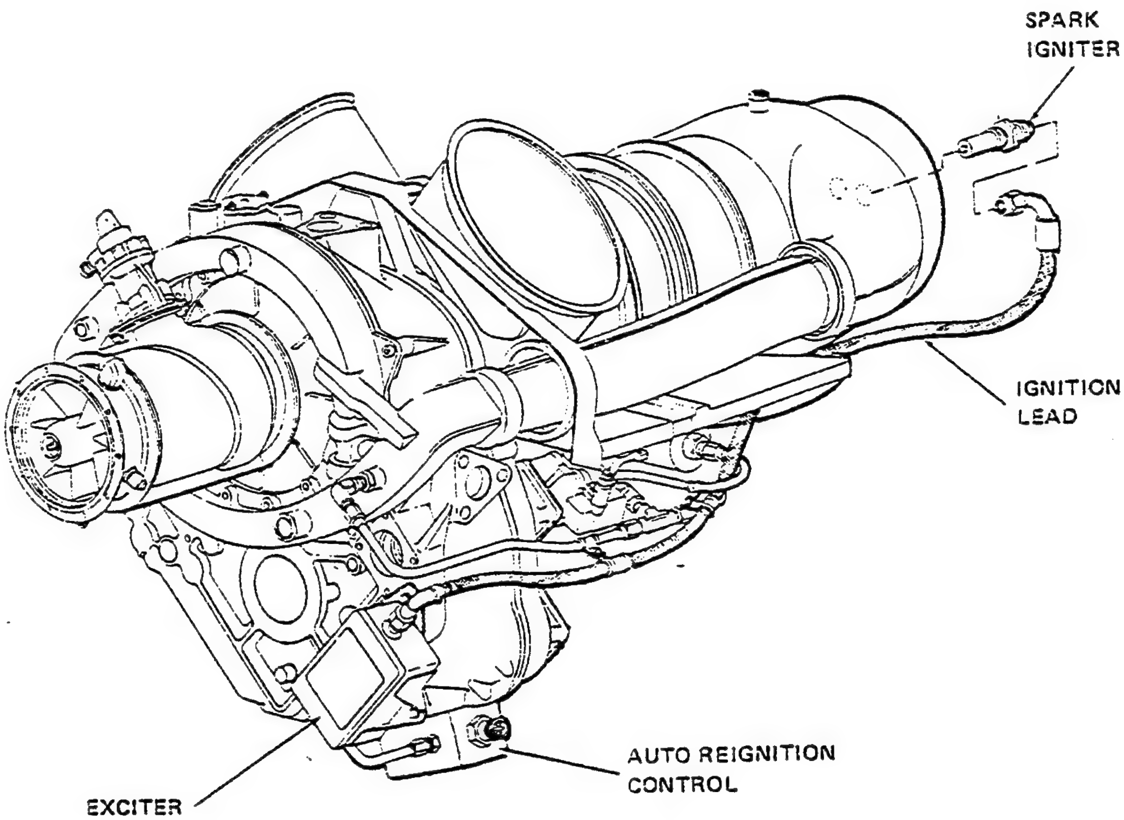


Figure 2.10. T63-A-700 Electrical Ignition System.
"From Ref. [2]."

III. DYNAMOMETER DESCRIPTION

A. INTRODUCTION

The engine dynamometer test system is a model SF-901 dynamometer which is manufactured by Superflow Corporation, Colorado Springs, Colorado. Since the principal application for the SF-901 test system is high performance internal combustion engine testing, various modifications were made to the existing system in order to facilitate compatibility with a gas turbine engine.

In this chapter, the principles of operation and major system components are discussed along with proposed console operations and configurations. A discussion of the structural modifications to the engine stand for mounting of the T63-A-700 engine is presented along with figures showing mounting details and measurements. Lastly, a description of the shafting modifications, as well as, the procedures used to determine shaft natural frequencies is introduced.

B. PRINCIPLES OF OPERATION

The gas turbine engine is mounted via a direct coupled shaft to a water brake dynamometer. The SF-901 dynamometer employs a water brake power absorption unit to provide loading for the power turbine. The maximum capacity of the power absorption unit (SF-801) is a torque of 1,000 FT-LB with a maximum rotational speed of 10,000 RPM for normal, continuous operation. However, the power absorber has the capability to withstand 12,000 RPM for brief periods with resultant reduced bearing life. Although this system is used principally for testing of internal combustion engines, it is quite sufficient to

handle the power requirements of the T63-A-700 gas turbine engine which transmits a maximum torque of 293 FT-LB with a normal output shaft speed of 6,000 RPM. A torque verses speed curve is presented in Figure 3.1 and shows an approximate torque curve for the engine superimposed with the maximum torque capacity curve for SF-801 power absorber. One can see for operating speeds greater than 2,200 RPM, the dynamometer will handle the engine torque quite effectively.

The SF-901 test system includes an engine stand, an engine cooling tower, a fuel system, and a 486 IBM compatible computer and printer system. Measuring devices for air flow, fuel flow, and oil pressure and their respective temperatures are also included.

C. MAJOR SYSTEM COMPONENTS AND ASSEMBLIES

1. Engine Stand

The engine stand, which is supported by four large casters for mobility, is the basic support structure for the engine, power absorber, fuel system, and cooling tower as shown in Figure 3.2. The engine stand also provides the instrumentation connections from all sensors and measurement devices to the dynamometer control console. An oil drip pan, battery storage rack, and water sump tank are also mounted on the engine stand.

2. Power Absorption Unit

A water brake power absorption unit is utilized to provide the necessary engine loading for adequate engine testing and performance analysis. The power absorber, filled with pressurized water, contains an impeller which resists the rotation of the engine output shaft thereby loading the engine. An external, closed water system, discussed in

Chapter V, provides a pressurized water supply to the power absorber for engine loading, as well as, cooling water to the water brake.

A LOAD CONTROL switch, located on the control console as shown in Figure 3.3A, adjusts the load applied to the engine by the power absorption unit. A rapidly variable water valve, which is located at the absorption unit discharge, regulates the discharge of water from the power absorber to maintain the required pressure within the absorber for proper load control. The load control can be operated in two modes, MANUAL and SERVO. In MANUAL mode, the load control maintains the same load on the engine at all RPM. When operated in SERVO mode, the load is variable and maintains a constant engine RPM regardless of throttle position. With this dual mode capability, it is possible to start the engine and idle in MANUAL mode at one constant load. After warm up, the operator can switch to SERVO mode and take the engine to full throttle for engine testing. A capacity valve, which is shown in Figure 3.3B, is used to adjust the dynamometer power absorption capacity. This is useful in controlling the sensitivity of the load control adjustment knobs by setting the capacity valve at the maximum load capability so that the full operating range of the absorption unit may be utilized during engine testing. [Ref. 5: p. 3.2-3.3]

3. Control Console

The control console uses a Motorola 6809 microprocessor to display and record data from the sensors on the engine test stand. The control console has four mirror scale analog meters and two digital displays for monitoring temperatures, voltages, power, torque, engine RPM, fuel flow rate, and air flow rate. A picture of the dynamometer control console is shown in Figure 3.4.

a. POWER ON Button

The POWER ON push-button turns on the 115/230 VAC power to energize the console thereby illuminating and enabling the engine starter push button and the ignition fuel pump switches. Pressing the POWER ON push-button a second time will de-energize the console and secure power to the engine ignition, starter, and dyno fuel pump. All test data is retained in the memory of the microprocessor when the console is de-energized.

b. IGNITION Switch

The IGNITION switch turns on the power to the engine stand ignition relay switch supplying battery power to the gas turbine engine's exciter and igniter. The IGNITION switch also opens a solenoid valve which provides dyno prime water to the power absorption unit.

c. FUEL PUMP Switch

The FUEL PUMP switch energizes the engine stand relay thereby supplying battery power to the dynamometer fuel pump. When the dyno fuel pump is energized, the fuel shutoff valve, which is solenoid operated, is open. In the event of a casualty, this safety feature is the principal means for rapidly securing fuel to the engine. Therefore, the first immediate action for all casualties will be securing power to the fuel pump which in turn closes the solenoid trip valve. By wiring the solenoid operated shutoff valve is this manner, control of the gas turbine is maintained in the event of loss of electrical power to the control console or the entire facility. This added safety feature is not

part of the SF-901 test system, but a modification to provide a quicker and more positive response in the event of a major casualty.

d. STARTER Button

The STARTER push-button energizes the engine stand relay that supplies battery power to the starter / generator on the gas turbine engine which in turn mechanically rotates the gas generator rotor. There is also an auxiliary starter switch on the engine stand front panel that allows local starting of the engine from within the test cell. However, in order to prevent an inadvertent start of the engine, this switch will be disabled .

e. LOAD CONTROL

A LOAD CONTROL, shown in Figure 3.3A, adjusts the load applied by the power absorption unit on the engine. The load control operates in two modes, MANUAL and SERVO. In MANUAL mode, the load control maintains the same load on the engine at all RPM. When operated in SERVO mode, the load is variable and maintains a constant engine RPM regardless of throttle position. A more complete description of the load control capability of the power absorption unit is discussed in Section 2 of this chapter.

f. TEMPERATURE METER Knob

The TEMPERATURE METER knob selects any of six temperature sensor outputs, as well as, servo valve load position, throttle position, and battery voltage to display on the control console TEMPERATURE METER. The TEMPERATURE

METER, which is one of the four mirror scale analog meters, is scaled in increments of 0-300 °F and 0-20 Volts to facilitate both temperature and position readouts. The Carburetor Air Temperature (CAT) thermocouple is installed in the air flow turbine flow meters mounted in the inlet plenum. This position allows the probe to measure the air temperature prior to entry into the gas turbine compressor. The WATER IN and WATER OUT temperature sensors measure the inlet water temperature and discharge water temperatures for the power absorption unit. The oil inlet (OIL IN) thermocouple is installed in the inlet piping prior to entering the gas turbine oil pump supply elements, and the oil discharge (OIL OUT) thermocouple is installed in the oil piping on the externally mounted oil cooler inlet. A thermocouple is installed in the dynamometer fuel piping to measure the inlet fuel temperature (FUEL T).

The servo valve load position (LOAD) for the power absorption unit can also be determined from the volt scale (0-20 Volts) on the TEMPERATURE METER. A "0" Volt reading shows the servo valve is in the fully open position indicating minimum load while a "20" Volt reading indicates that the servo valve is in the fully closed position for maximum loading. During engine light off in accordance with Master Lightoff Procedure (MLOP), the load control is positioned at "8" Volts. The throttle position (THROTTLE) can also be determined from the voltage scale. A "0" Volt reading indicates that the throttle is fully closed, and a "20" Volt reading indicates a wide open throttle. The TEMPERATURE METER is also connected to the engine stand batteries and allows the console operator to monitor the battery supply voltage.

g. TORQUE-POWER and SPEED DISPLAY Knobs

The TORQUE-POWER and SPEED DISPLAY knobs are used to adjust the scales on the TORQUE-POWER and SPEED mirror scale analog meter. The HIGH / 10,

LOW, and HIGH positions indicate ranges of (0-100), (0-500), and (0-1,000) FT-LB or SHP respectively. The normal configuration for the T63-A-700 gas turbine is the LOW (0-500) scale. The SPEED knob has a LOW speed scale (0-6,000 RPM) and HIGH speed scale (4,000-12,000 RPM). Since the 100% design output shaft RPM of the gas turbine engine is 6,000 RPM, the LOW scale will be used for most applications.

h. AIR-FUEL and Vapor Pressure Knobs

The AIR-FUEL meter knob selects whether fuel flow or air flow is read on the rightmost mirror scale analog meter. The meter is scaled in 0-400 LB/HR or 0-12,000 SCFM for this dual capability. A FUEL/2 and an AIR/2 selection allows the operator to double the scale range to 800 LB/HR and 24,000 SCFM. The vapor pressure (VAPOR PRES. IN. HG.) knob is used to input the water vapor pressure as determined from the sling psychrometer and the Temperature to Water Vapor Pressure Conversion Graph contained in the dynamometer instruction manual [Ref. 5: p. 3.8]. The dynamometer computer uses the water vapor pressure, carburetor air temperature, and barometric pressure to determine air density. Using these parameters, the dyno test system calculates the true air flow rate and the power correction factors for engine testing analysis.

i. Fuel Specific Gravity and FUEL MODE Knob

The fuel specific gravity (FUEL SPEC. GRAVITY) knob is used to input the fuel specific gravity determined from a floating hydrometer. The FUEL MODE knob, which has four modes of operation, provides the capability to measure fuel flow to dual pumping elements and dual carburetors. Since the gas turbine engine fuel pump has only one fuel inlet, the system will only be used in configuration A.

j. OVERSPEED Knob and Warning Light

The OVERSPEED system grounds the ignition coil when the engine output shaft speed exceeds the speed set on the OVERSPEED knob. When the OVERSPEED system is activated, the OVERSPEED indicator light will flash in the lower digital meter display. Since the gas turbine engine does not use an ignition coil when the sustained run speed is reached, the dynamometer OVERSPEED system will be used only as a warning indicator for an output shaft overspeed. Output shaft speed will be monitored from the SPEED mirror analog meter on the control console, but the gas generator and power turbine speed will be monitored from separate digital meters installed on the top of the dynamometer control console. Overspeed trip relays will be installed which secure power to an electric solenoid valve in the fuel inlet piping. Therefore, an overspeed of either the power turbine or gas generator will secure the dynamometer fuel pump. The gas generator overspeed trip will be set at 51,120 RPM (100%), the power turbine overspeed trip will be set at 35,000 RPM (100%), and the output shaft speed trip will be set at 6,000 RPM. As specified in the installation design manual, the engine is designed to withstand speeds of 105% for 15 seconds. The recommended trip settings for both the power turbine and gas generator turbine speeds are 104%. [Ref. 1: p. 1-3] However, the engine overspeed trips will be set 100% for an added margin of safety in the gas turbine test facility.

k. Oil Pressure Gauge and Vacuum Gauge

A mechanical oil pressure gauge (0-160 PSIG) is attached by a connecting line to an input on the engine stand panel. Another connecting line is used to connect the engine stand panel to a pressure connection on the front of the gas turbine's accessory

gearbox. The dynamometer has a 15 PSIG pressure switch mounted on the back of the oil pressure gauge in the control console that triggers a warning light in lower digital display, which is shown in Figure 3.5. When the system oil pressure drops to below 15 PSIG, the warning light will flash. Since the normal engine operating pressure is between 110-130 PSIG, this switch will be modified to make the low pressure warning light activate at 90 PSIG, and the emergency shutdown of the fuel solenoid will be set at 50 PSIG. The vacuum gauge on the dynamometer control console is intended to be used to measure crankcase vacuum or manifold vacuum on internal combustion engines and is not used in the gas turbine installation.

1. Warning Lights

Six warning lights associated with the engine and dynamometer operation are displayed in the lower digital display (Figure 3.5) on the dynamometer control console: oil pressure, overspeed, water supply, dyno prime, water temperature, and fuel pressure.

The OVERSPEED and OIL PRESSURE warning light indications are discussed above in subsections J and K respectively. The WATER SUPPLY warning light indicates a supply water pressure to the dynamometer power absorber that is less than 15 PSIG and requires an emergency stop of the engine by tripping the fuel pump thereby, closing the fuel solenoid shutoff valve. The DYNO PRIME warning light indicates that the dynamometer power absorber must be reprimed. This also requires an emergency shutdown of the engine for repriming. The WATER TEMP. light indicates that the water temperature from the power absorber discharge is above 210 °F. This requires a shutdown of the engine to prevent an engine overspeed caused by possible water vaporization within the power absorber. The FUEL PRESSURE light will illuminate when there is less than 4

PSIG fuel supply pressure. All emergency shutdowns are to be completed in accordance with the Emergency Shutdown Procedure (ESP) discussed in Chapter VII.

m. Engine Testing Control Knobs

The remaining knobs and push-buttons are dedicated to detailed engine testing and performance evaluation and not in basic engine operations, thus these operators will not be discussed.

4. THROTTLE SYSTEM

The engine throttle system consists of a two hydraulic cylinders, a throttle lever, a throttle arm, and a throttle control wire as shown in Figure 3.6. The two cylinders, one located inside the control console and the other on the engine stand, are connected by 3/8 inch diameter tubing and use water as the working fluid between them. When the throttle control lever is actuated on the control console by the operator, water is sent from the hydraulic cylinder in the control console to the cylinder on the engine stand. The cylinder in turn strokes the throttle arm and control wire that is connected to the power turbine speed control.

In order to utilize the T63-A-700 gas turbine engine in the ME 3241 course and conduct the engine performance evaluation as discussed in Chapter II, the gas generator speed is required to remain fixed while varying output shaft speed and in turn the power turbine speed. Ongoing research is being conducted with Allison Engine Co. [3] to solve this problem.

5. Cooling Tower

The Superflow 901-SF dynamometer also contains a cooling tower in lieu of a radiator for internal combustion engine systems. Since the gas turbine engine is air cooled, the cooling tower is not installed on the engine test stand.

6. Fuel System

The dynamometer fuel system consists of a fuel filter, pump, accumulator, and flow sensors for two parallel fuel outlets. Detailed system schematic are presented in the dynamometer instruction manual. [Ref. 5: p. 11.10-11.11] The two parallel fuel outlets are available for dual injection and dual carburetor systems. Since the gas turbine fuel control has only one fuel line available, the second fuel line is not utilized. The dynamometer fuel system receives fuel from the auxiliary fuel supply system (see Chapter V.B) through two FRAM fuel filters. The fuel then enters the inlet of the fuel pump through a 10 micron filter mounted on the engine test stand. The fuel pump discharges into the accumulator and flows through the turbine flow meter into the inlet of the gas turbine gas generator fuel control via fuel shutoff solenoid. The dyno fuel pump provides fuel at 1 GPM and the accumulator maintains a supply pressure of 12 PSIG. A return connection is also installed to route excess fuel back to the fuel tank.

7. Sump Tank

The sump tank is a segregated tank that is mounted on the engine stand and is open to the atmosphere. The sump tank provides both local water supply storage to and

discharge from the power absorption system. Water enters the sump tank from the external auxiliary water supply system through a float control valve which shuts off the water supply to the sump tank. The float control valve utilizes a float and arm assembly to secure water to the sump tank and prevent overflow during low power demand conditions. The power absorber impeller takes suction from this tank and discharges the water back to atmosphere on the segregated side of the sump tank. An auxiliary return pump, which is located in the test cell, takes suction and returns the water to the storage tank on the auxiliary machinery pad.

8. Electrical System

The dynamometer electrical system consists of both direct current and alternating current systems. The dynamometer computer, printer, and control console utilize 115 VAC single phase power provided by the building's electrical system. The engine stand fuel pump, instrumentation, and control circuitry utilizes 12 VDC power supplied by two, 12 Volt batteries stored in the battery rack mounted on engine stand. A 12 Volt power switch, which is connected to a single 12 Volt battery, provides electrical power to the engine stand components while the two batteries wired in series provide 24 VDC to the engine starter / generator.

D. MOUNTING MODIFICATIONS

In order to make the Superflow 901 engine stand capable of mounting the T63-A-700 gas turbine engine, four major structural modifications were made to the engine stand and the gas turbine engine.

1. Shafting Modification

One of the most important design considerations in mounting of the gas turbine engine to the dyno engine stand was placement of the engine in such a manner as to avoid obstructed air flow to the compressor causing a decreased stall margin. In the OH-58 helicopter airframe the rotor blade is driven via a free wheeling assembly connected to the engine's accessory gear under the compressor assembly. Mounting of the engine such that the free wheeling assembly is used to drive the water brake was not suitable since the engine placement caused the air flow to be obstructed by the power absorber and instrumentation rack. Because of this problem, a suitable alternative was sought.

After consultation with Allison Gas Turbine [6], it was determined that the engine could be loaded from the rear tail rotor connection. However, preliminary Strength of Materials calculations revealed that the tail rotor shafting, as used in the OH-58 helicopter, was not strong enough to handle the full engine torque.

The torsional shear stress, τ, [PSI] is given by:

$$\tau = Tc/J \qquad (3.1)$$

where T(torque)=293 FT-LB at maximum power, c is the outer radius of the hollow shaft (FT) and J is the radius of gyration (FT^4). This was used for a preliminary design of the drive shaft with τ_{max} ~ 30,000 PSI.

By changing the engine mounting from a forward drive to a rear drive configuration, an additional problem was encountered; the dyno power absorber was not configured for the reversed shaft rotation. This problem was solved by manufacturing a bi-directional package for the dyno power absorber, allowing for reverse rotation of the water brake.

Lastly, the tail rotor shafting had to be replaced. Once again, after consultation with Allison Gas Turbine, an engine test cell design company was determined to possess the capability and had experience in manufacturing shafting for such an application [4]. The shaft, designed and manufactured by Turbomotive Inc., was deemed suitable since it was sturdy enough to handle the full engine torque and provided for direct splining of the shaft to the reduction gearing in the engine. This attribute allowed for removal of the free wheeling assembly and provided a balanced and reliable drive shaft for engine operation. A picture of the shafting is shown in Figure 3.7. After solving the above problems, the decision was made to mount the engine and drive the water brake from the tail rotor connection. This decision was tcornerstone to the design of the rest of the structural supports for the engine mounting.

Upon receiving the output shaft, a pulse excitation impact test was conducted to determine the shaft's natural frequencies. The shaft was suspended from a Bungy cord on both ends and an accelerometer was mounted to the shaft in various locations. The shaft was then impacted with a pulse excitation transducer (hammer), and the shaft's natural frequencies were recorded via a data acquisition system. Data were recorded for various accelerometer locations, and the Mode 1 natural frequency (lateral bending) of the shaft was found to be 375 HZ (22,560 RPM). This result was very suitable since the maximum shaft speed is 6,000 RPM (100 HZ). Therefore, the operator does not have to be concerned with passing the shaft through a resonant natural frequency during gas turbine testing. The graphical result of the pulse excitation impact test is shown in Figure 3.8. A theoretical

natural frequency (w_n) was calculated to be 7,200 RPM (120 HZ) for a simply supported shaft (pin-pin) with the equation:

$$w_n = \Pi^2 * (EI/\rho AL^4)^{1/2} \qquad (3.2)$$

where E is the modulus of elasticity [PSI], I is the moment of inertia [IN^4], ρ is the density [LB/IN^3], A is the cross sectional area [IN^2], and L is the shaft length [IN].

2. Front Support

Since the engine mounting brackets, delivered with the dyno engine stand were intended for an internal combustion engine, an entire front support for the engine was designed and fabricated from 6061-T6 aluminum. From a practical standpoint, the design philosophy was to use the existing attachment points on the engine housing normally used for mounting the engine in the helicopter airframe.

The front support uses a three point mounting approach as shown in Figure 3.9 and 3.10. Mounting pads are utilized on both sides, as well as, the bottom of the accessory gear box. All supports are fastened together with grade 5 bolts for ease in disassembly for shimming and addition of vibration isolation mounts. An additional, single base plate will be added to the engine stand to facilitate shimming for more precise engine shaft alignment. It is intended to utilize the gas turbine engine for further thesis research in the area of vibration analysis, hence the importance of this capability. A detailed drawing with dimensions is included in Appendix A.

3. Rear Support

After mounting of the gas turbine on the front support, it was determined that a rearward eccentric moment was present that would place a large stress on the shafting bearings. In order to eliminate this design deficiency, an engine rear support was designed and fabricated as shown in Figure 3.9. This support, also made of aluminum, uses the mounting point under the combuster outer casing just forward of the combuster drain. The semicircular cutout provides a pass through for the engine drive shaft to the dynamometer. A detailed drawing of the rear support with dimensions is also included in Appendix A.

4. Torque Plate

The Superflow 901-SF test system utilizes a system of strain gauges attached to the power absorber to measure engine torque. This is quite suitable for internal combustion engines which do not utilize a connection shaft between the engine crankshaft and the power absorber drive spline. Since the gas turbine engine utilizes a connection shaft with flexible couplings, this set up is not capable of providing an accurate torque measurement. The purpose of the torque plate, which is shown in Figure 3.11, is to provide rigidity between the gas turbine engine and the power absorber thereby making the strain gauge configuration a workable means of measuring engine torque. A detailed drawing of the torque plate with dimensions is shown in Appendix A.

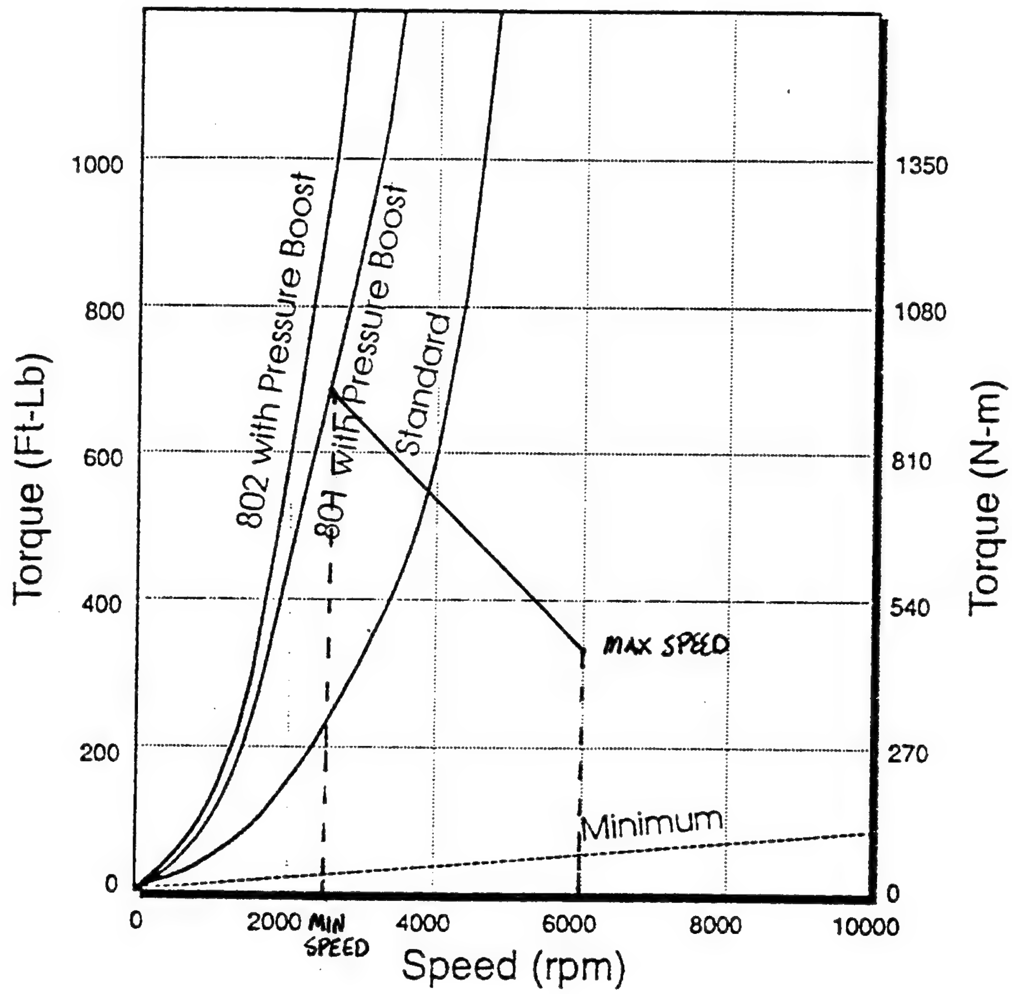


Figure 3.1. Torque Capacity Comparison Curves for Engine and Power Absorption Unit. "From Ref. [5]."

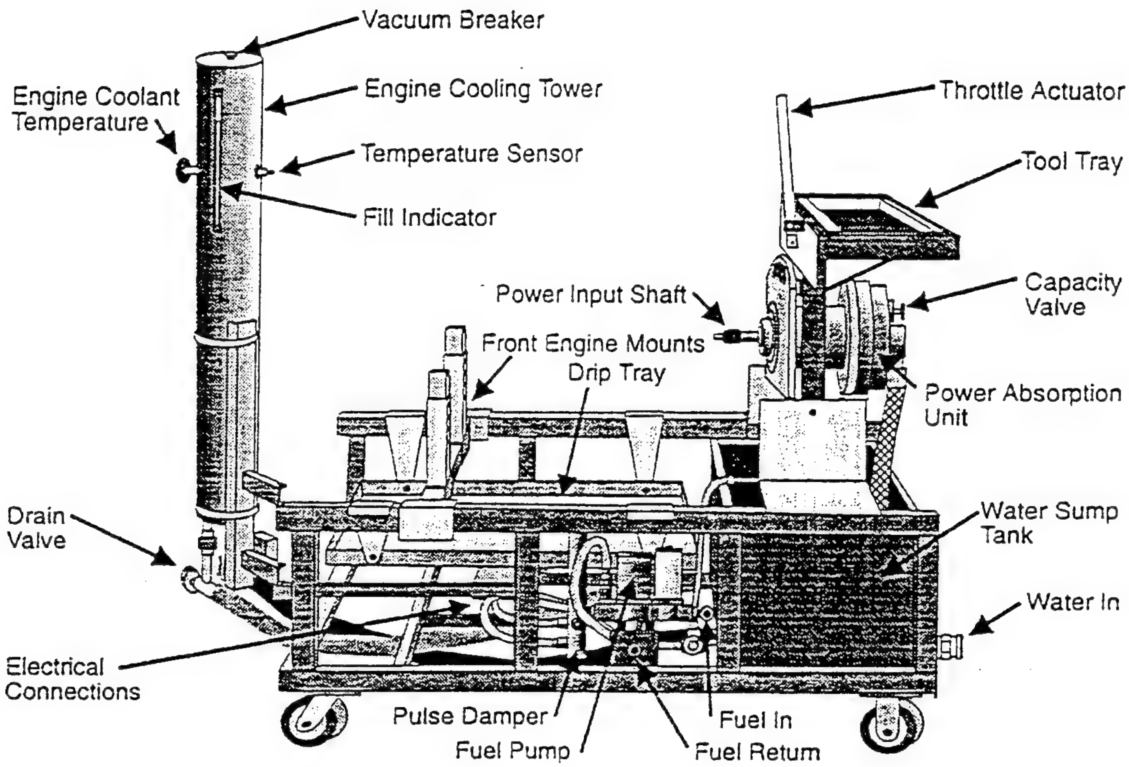


Figure 3.2. SF-901 Dynamometer Engine Stand.
"From Ref. [5]."

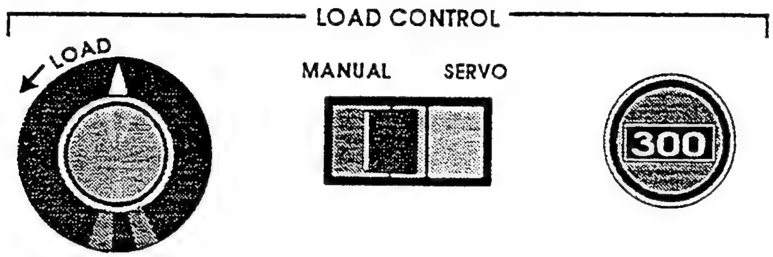


Figure 3.3A. SF-901 Dynamometer Load Control. "From Ref. [5]."

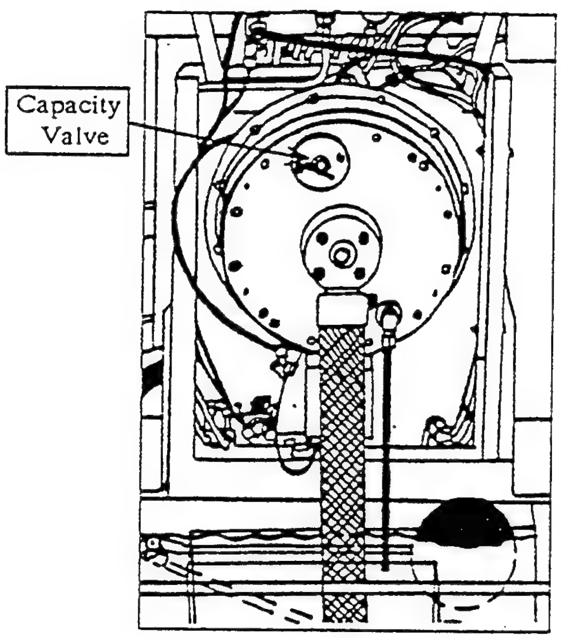


Figure 3.3B. Dynamometer Power Absorber and Capacity Valve. "From Ref. [5]."

Figure 3.4. Superflow SF-901 Dynamometer Control Console.

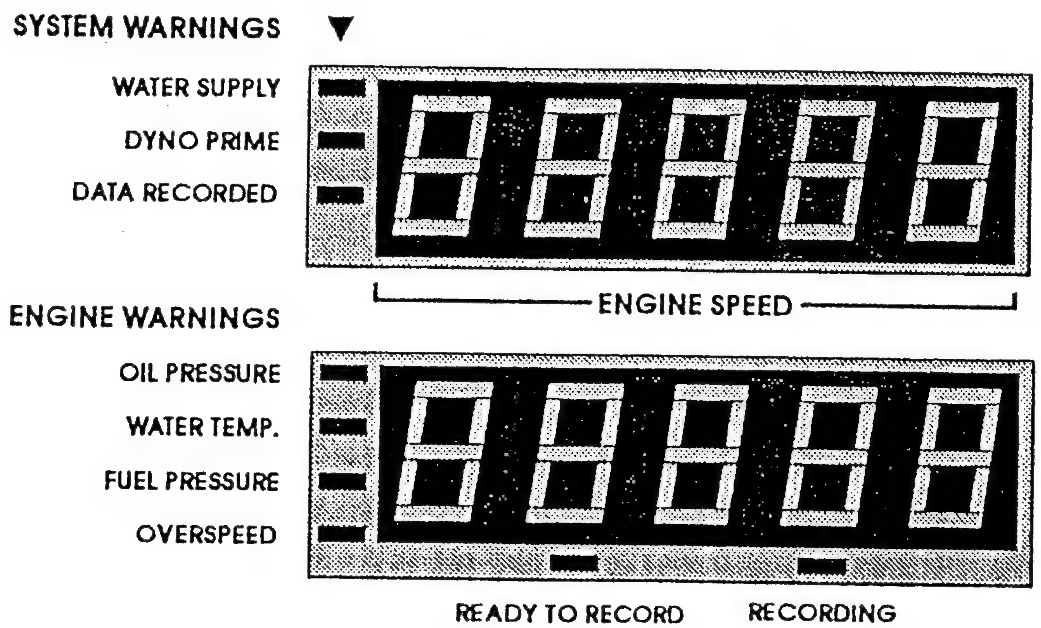
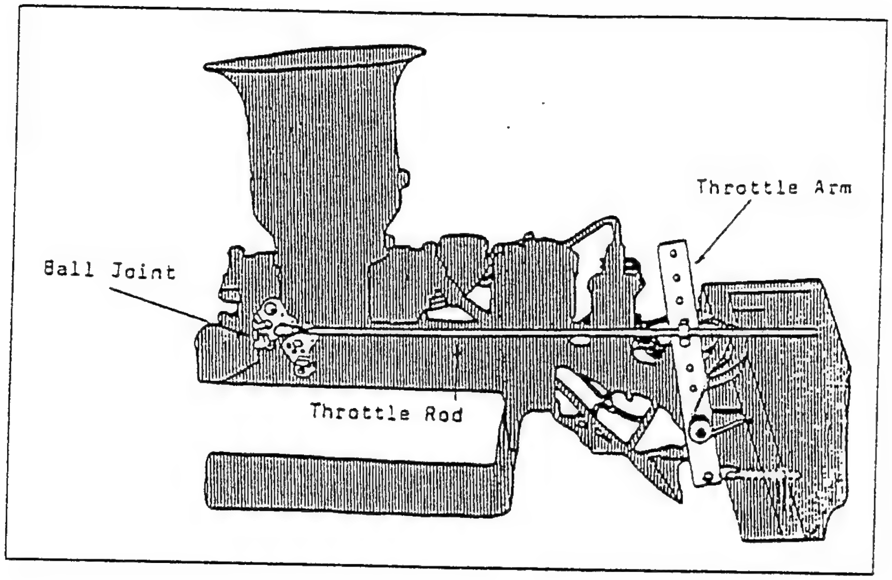


Figure 3.5. Control Console Engine Warning Lights and Digital Displays. "From Ref. [5]."



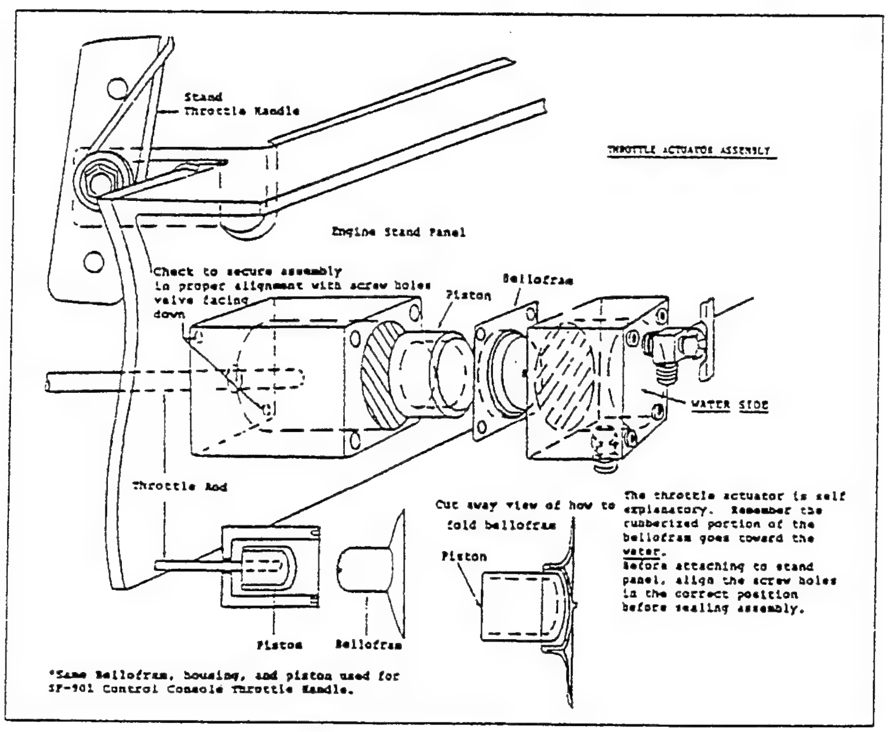


Figure 3.6. Dynamometer Throttle System.
"From Ref. [5]."

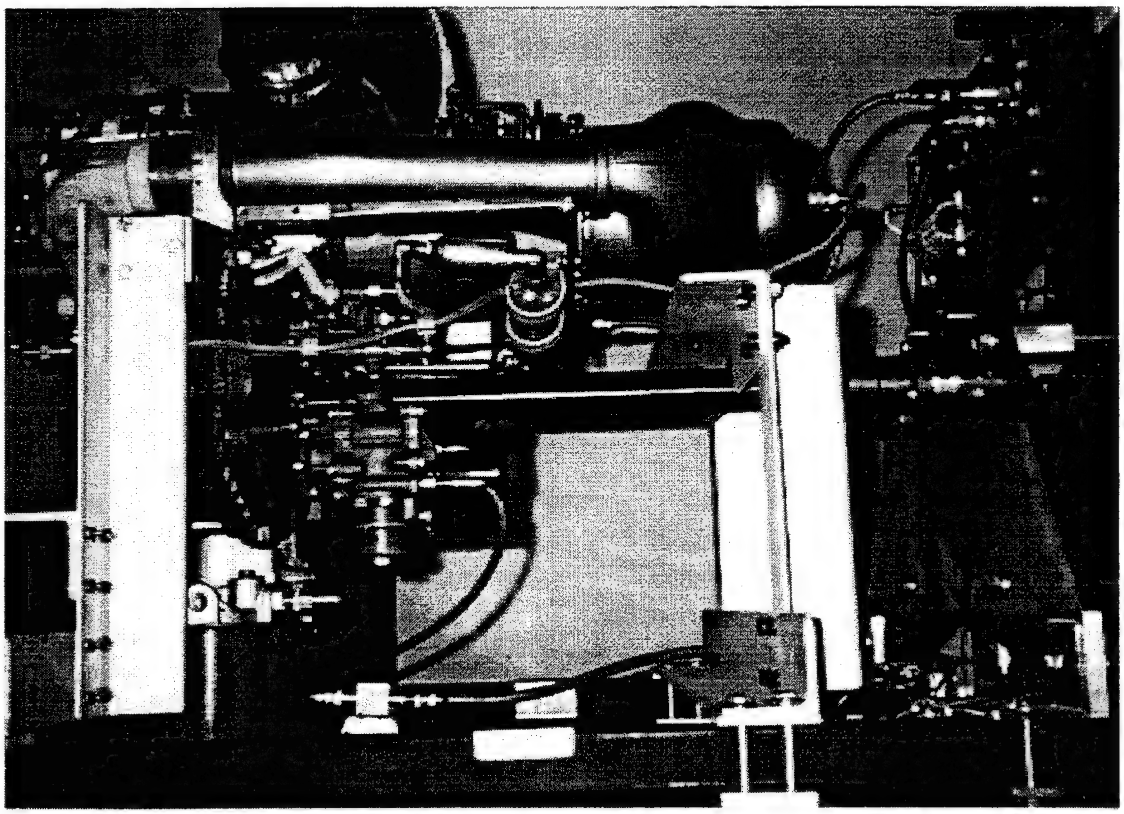


Figure 3.7. Output Drive Shaft.

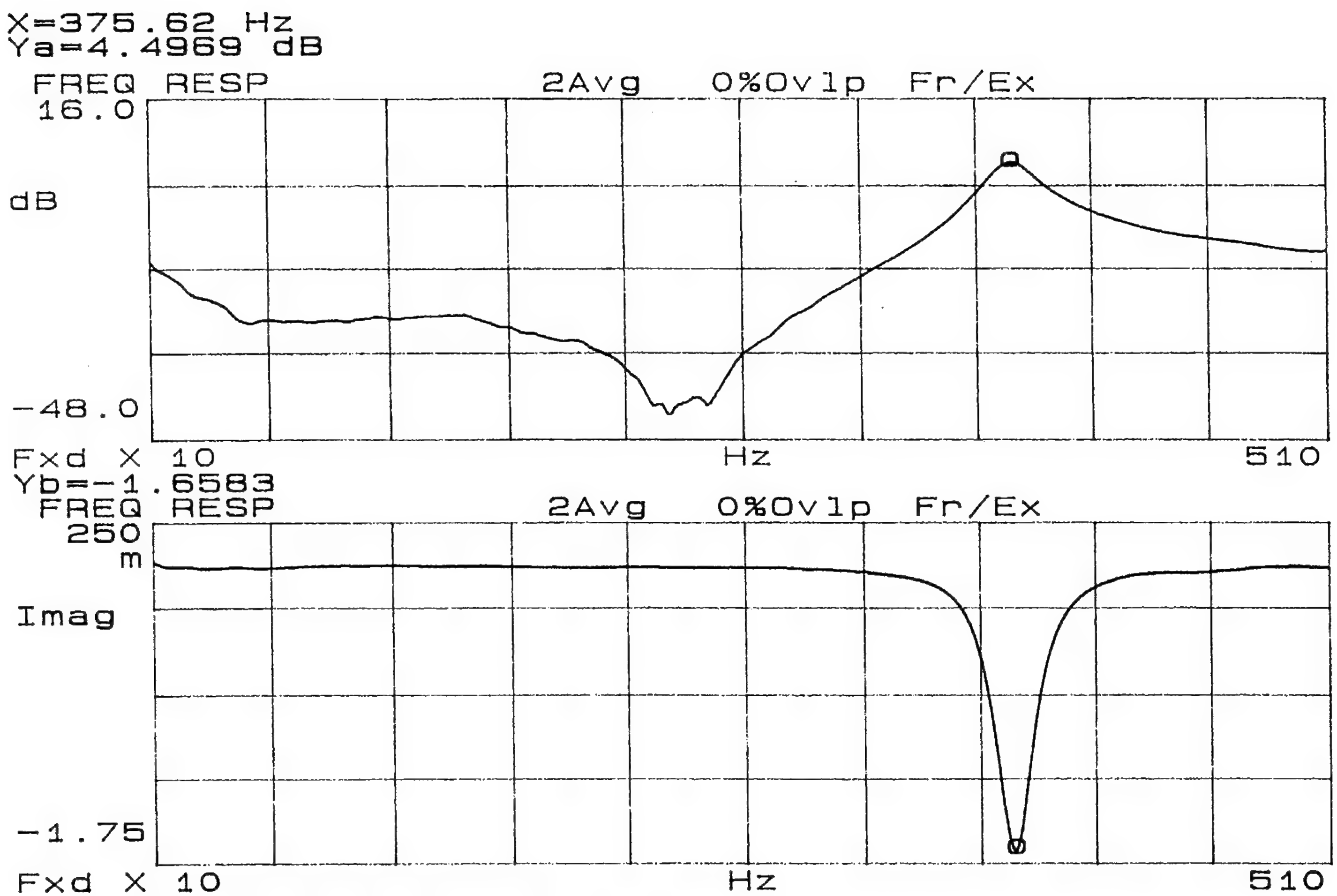


Figure 3.8. Graphical Result of the Pulse Excitation Impact Test on the Output Drive Shaft.

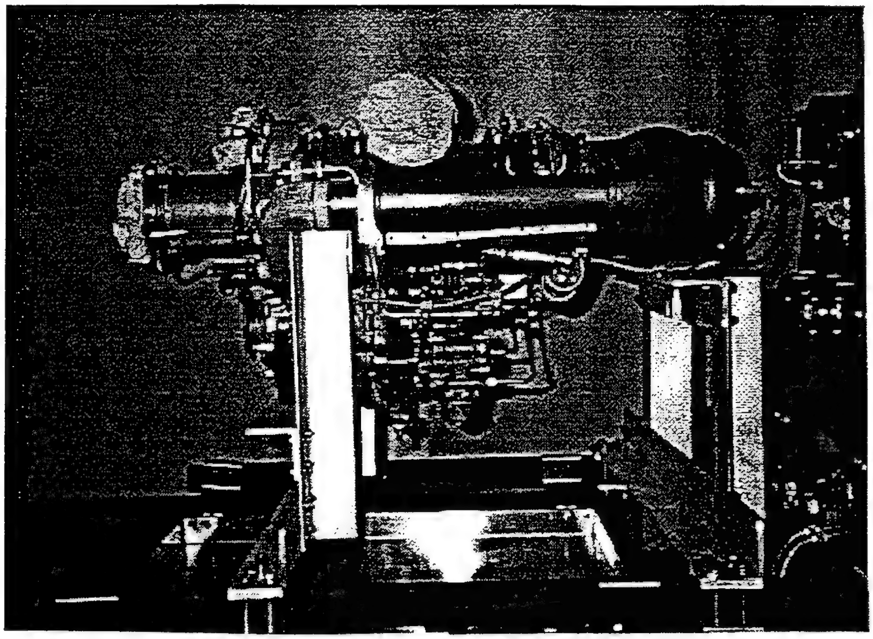


Figure 3.9. Photograph of Gas Turbine Rear Mounting Support.

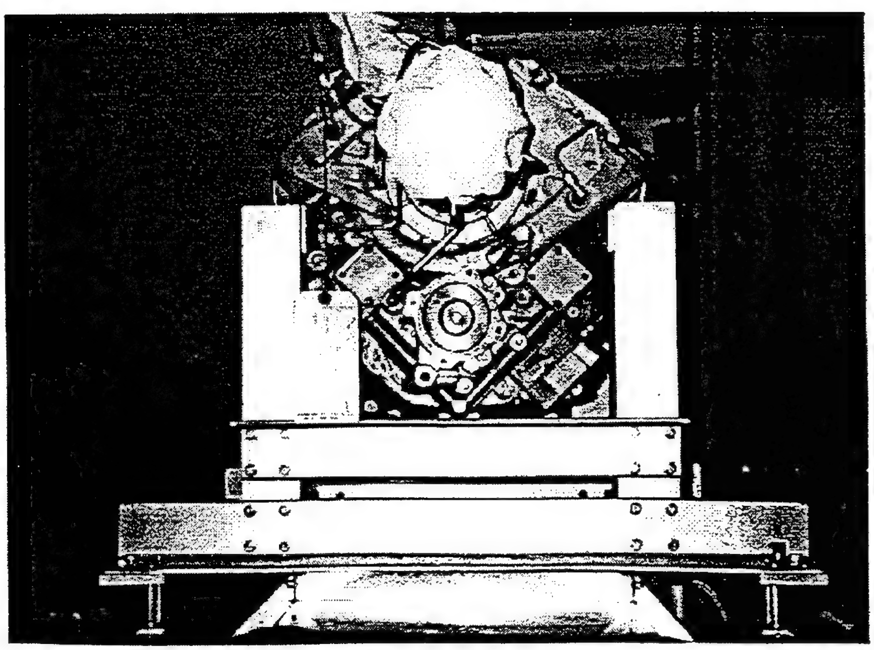


Figure 3.10. Photograph of Gas Turbine Front Mounting Support.

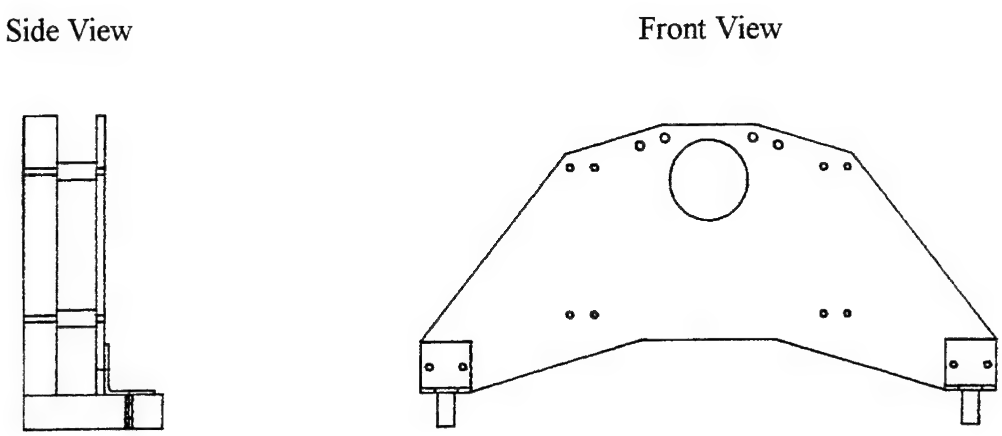


Figure 3.11. Dynamometer Torque Plate Adapter.

IV. GAS TURBINE TEST FACILITY

A. INTRODUCTION

The Marine Propulsion Laboratory is comprised of a gas turbine test cell, a Diesel test cell, a laboratory preparation / instructional area, and an auxiliary machinery equipment pad. The purpose of this chapter is to describe the physical layout of the Marine Propulsion Laboratory and Gas Turbine Test Cell, as well as, discuss the auxiliary systems which were designed to support gas turbine, Diesel, and dynamometer operations.

B. MARINE PROPULSION LABORATORY FLOOR PLAN

The Marine Propulsion Laboratory floor plan is shown in Figure 4.1. The laboratory preparation / instructional area, which is approximately 900 square feet in area, serves as a central location for gas turbine and Diesel documentation and also provides the necessary student study areas and computer availability for detailed analysis. The work area also contains the dynamometer control consoles and computer systems for both the Diesel and gas turbine test cells. The operator is separated from the engine test cells by an 18 inch concrete block wall, double paned shatterproof windows, and two vapor proof doors for safety considerations. Directly behind the Diesel and gas turbine test cells and outside of the building structure is the auxiliary machinery equipment pad.

C. AUXILIARY MACHINERY EQUIPMENT PAD

The auxiliary machinery equipment pad, which is approximately 600 square feet in area, is poured concrete and supports the water and fuel storage tanks, water and fuel oil service pumps, water filtration elements, and the water system heat exchanger. A detailed description of the auxiliary support equipment is discussed in Chapter V as part of the auxiliary support system design. A photograph of the auxiliary machinery equipment pad is shown in Figures 4.2 and 4.3. An equipment listing is contained in Appendix B.

D. GAS TURBINE TEST CELL

The gas turbine test cell is 30 FT X 15 FT X 9 FT and houses the gas turbine engine and dynamometer, as well as, instrumentation racks, a flammable liquids locker, and a fire extinguisher. Also enclosed within the cell are the piping runs for water and fuel, connections for low pressure air, a city water connection, a fire extinguishing sprinkler system in the ceiling, and electrical receptacles for 230 and 115 VAC. The concrete floor contains a trench network used for running system piping and catching effluent liquid. The piping trenches are 12 inches wide by 12 inches deep, and surround the engine and dynamometer. The trenches also provide pass throughs for piping and electrical wiring from the auxiliary machinery equipment pad and the laboratory preparation / instructional area into the gas turbine test cell. In order to provide sufficient operator and student safety along with adequate noise reduction, the test cell is enclosed by eighteen inch reinforced concrete, and the observation window is made of double pane shatter proof glass. The personnel entrance from laboratory preparation / instructional area is through double steel

doors which are vapor proof and add additional sound attenuation. The cell was designed to achieve a 30 dB sound attenuation.

The air intake for the cell enters the building through louvers (Figure 4.4) located directly above the auxiliary machinery equipment pad where the air ducting is turned ninety degrees and enters the test cells through the ceiling. The gas turbine exhaust ducting is also discharged through the ceiling of the cell and is routed through uptakes along the side of the building. Figures 4.2 - 4.6 are photographs of the Marine Propulsion Laboratory at various locations for added clarity.

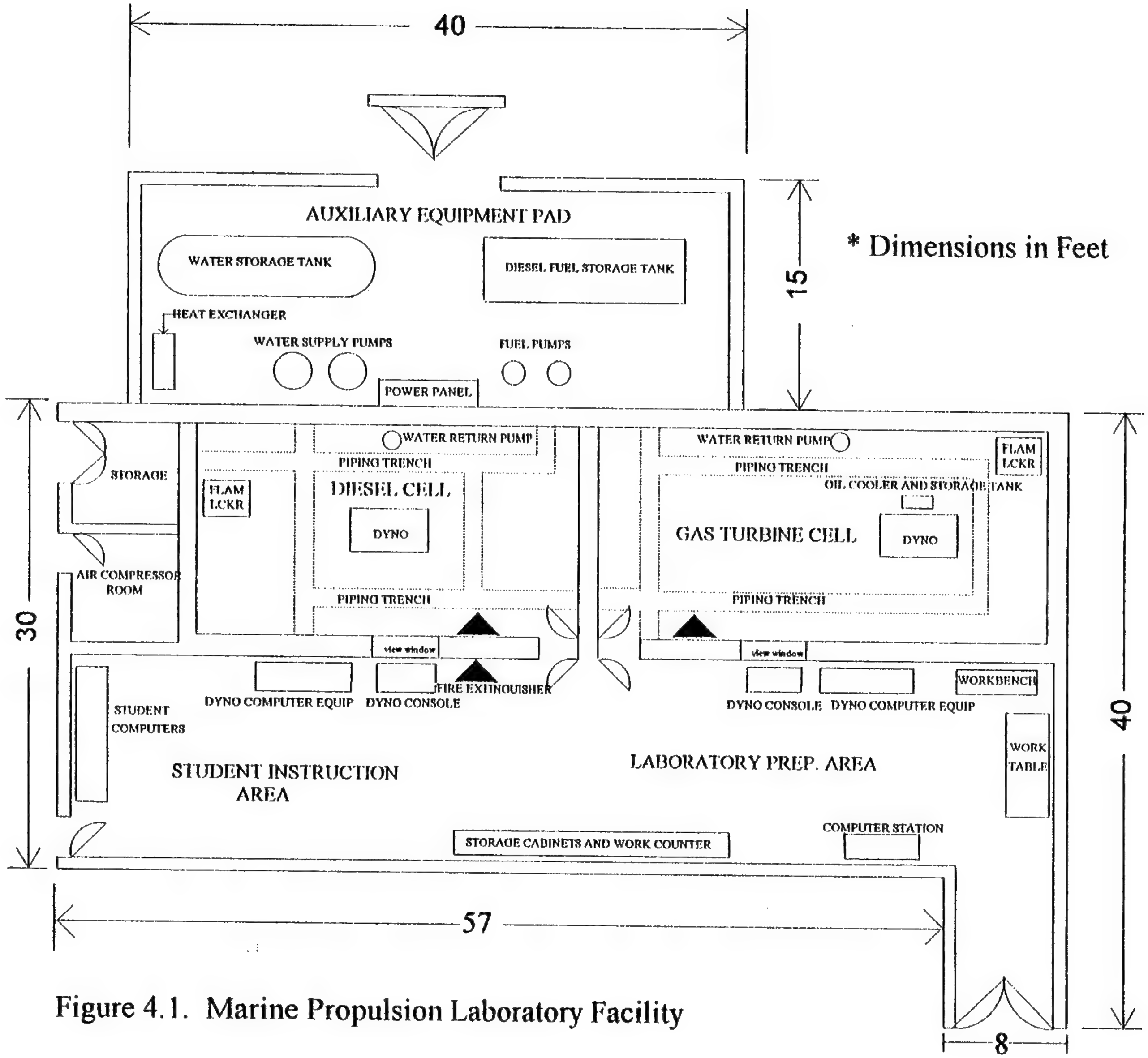


Figure 4.1. Marine Propulsion Laboratory Facility

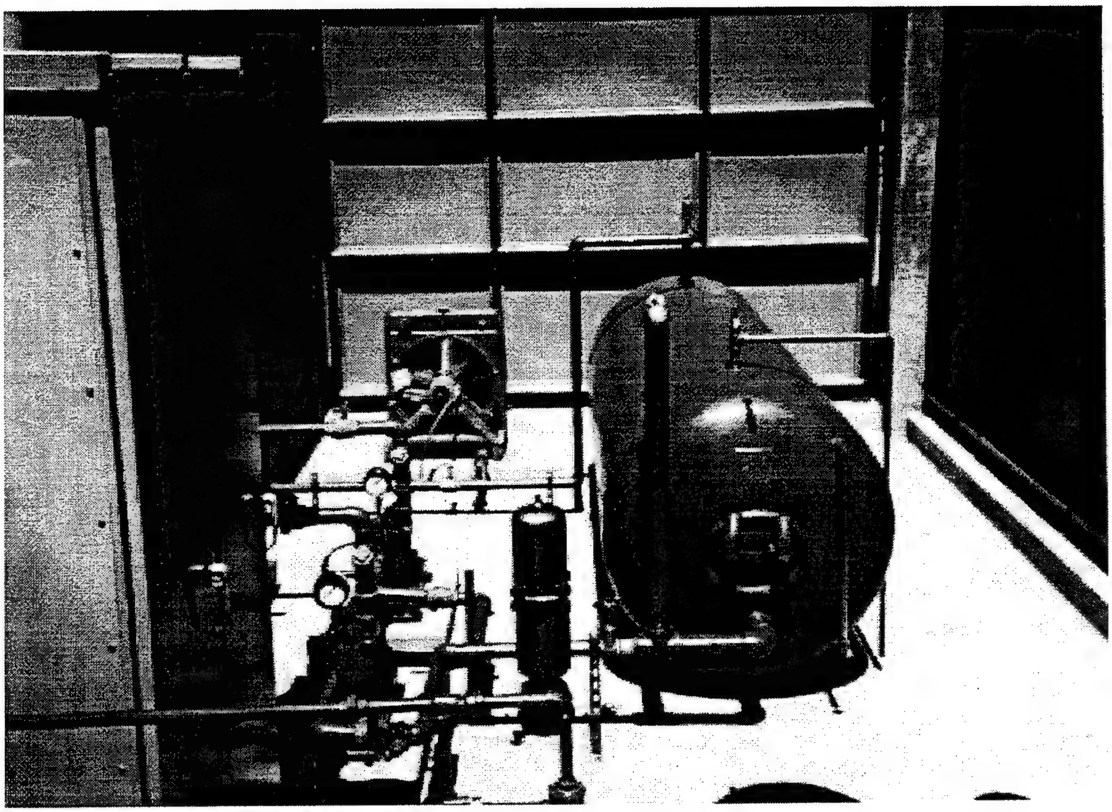


Figure 4.2. Auxiliary Machinery Equipment Pad (Water Side).

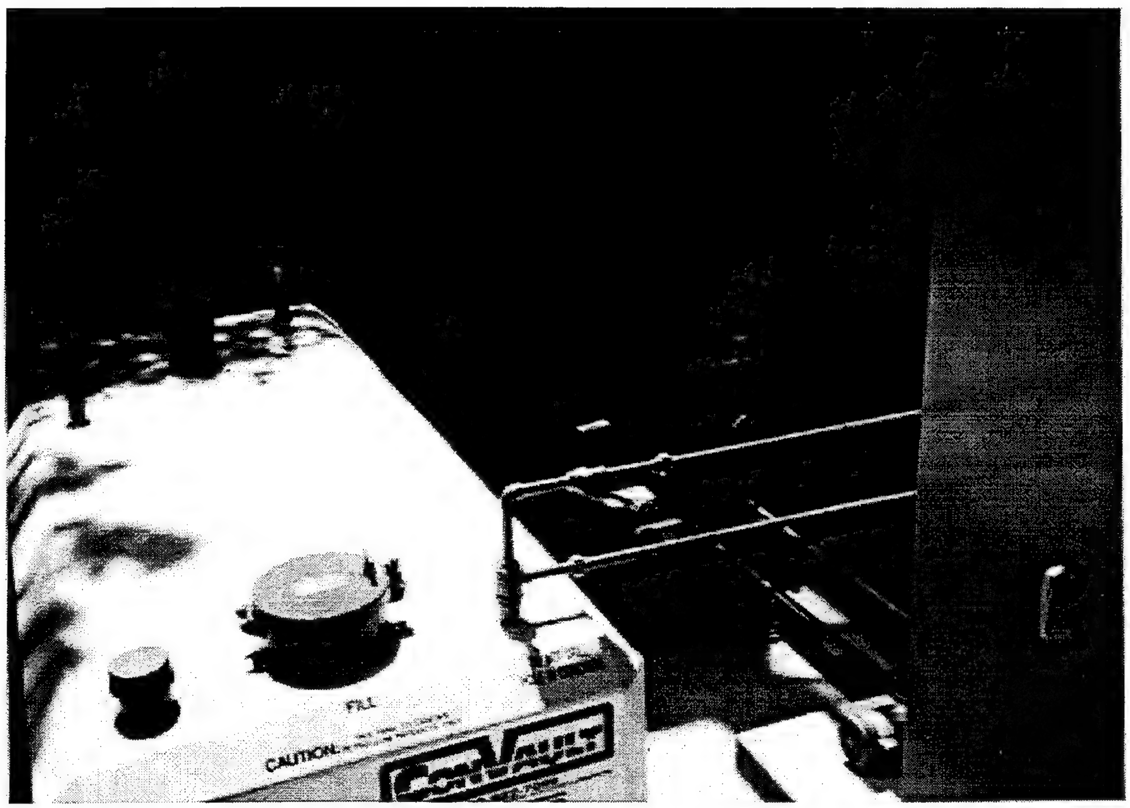


Figure 4.3. Auxiliary Machinery Equipment Pad (Fuel Side).

Figure 4.4. Air Intake Louvers.

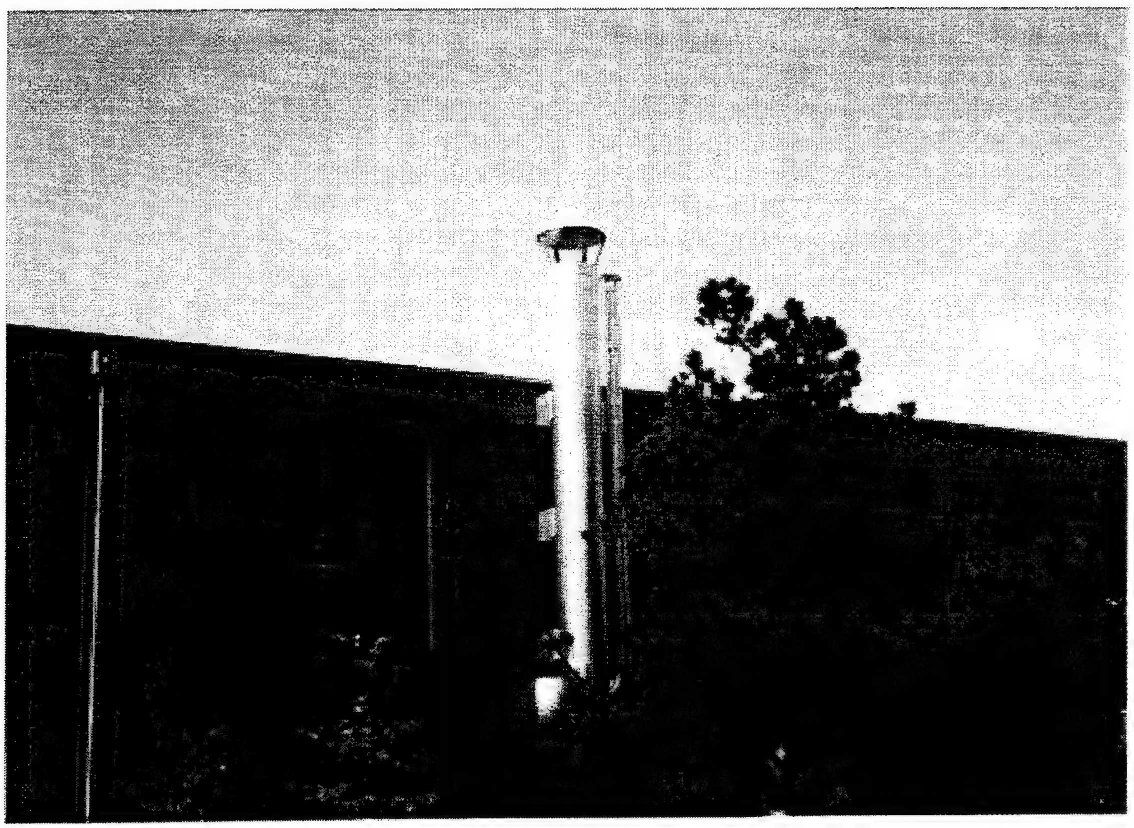


Figure 4.5. Exhaust Uptakes for Gas Turbine and Diesel Cells.

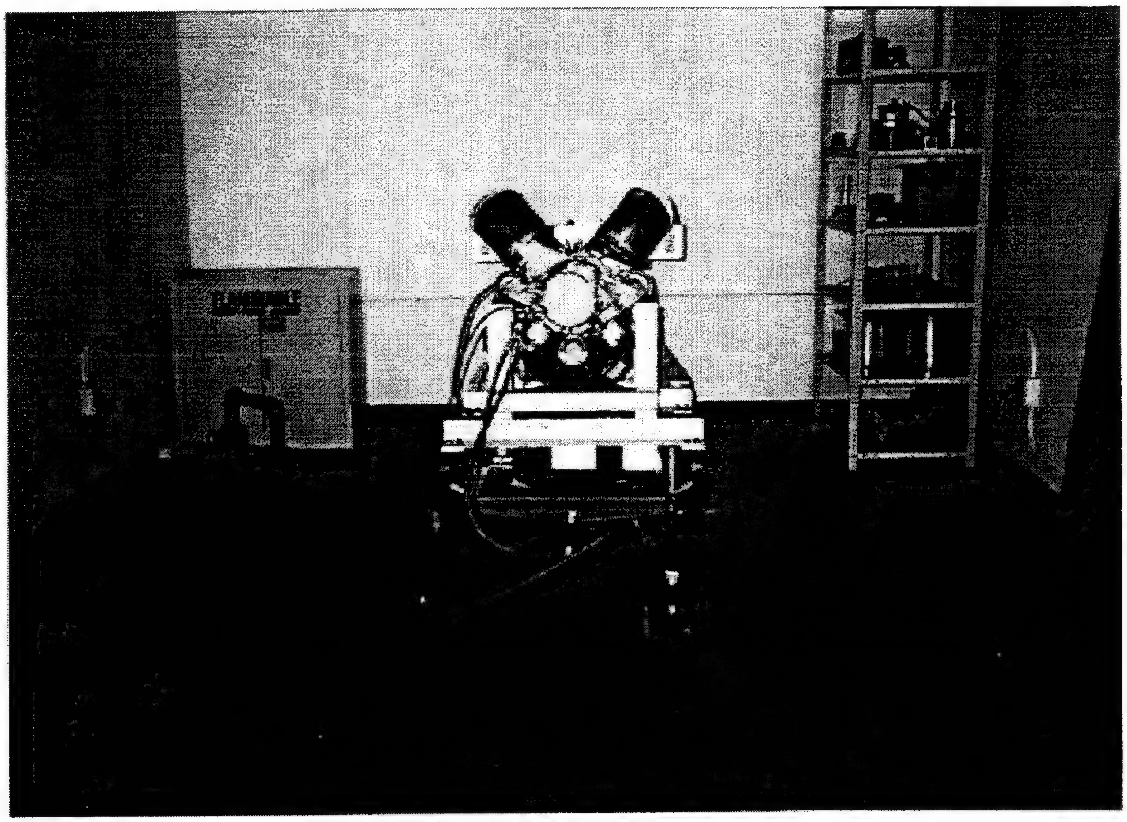


Figure 4.6. Gas Turbine Test Cell.

V. AUXILIARY SYSTEM DESIGN

A. INTRODUCTION

The purpose of this chapter is to discuss the design considerations and equipment selection for the auxiliary support systems which support T63-A-700 gas turbine engine and the Superflow 901-SF water brake dynamometer operations. Since the specifications for the auxiliary equipment were written as part of the building construction contract and not specifically for the T63-A-700 gas turbine and Superflow 901-SF dynamometer, numerous modifications were made to existing equipment in order to meet design requirements. The design criteria, system design, system schematics, and the actual equipment installation for the water, fuel, air, oil, and electrical systems for the gas turbine test facility will be discussed. A detailed equipment listing by system is enclosed in Appendix C.

B. WATER SYSTEM

The support function for the water system is to provide water pressure resistance and cooling water to the dynamometer power absorption unit's water brake impeller. A schematic of the water system is shown in Figure 5.1.

1. Design Criteria

The design criteria as specified by Superflow Corporation in the dynamometer manufacturer technical manual [Ref. 5: p.1.8-1.10] are summarized below:

* water flow requirement	1 GPM per 10 HP of engine load
* water supply pressure	35 PSIG min. / 60 PSIG max.
* dynamometer water discharge temperature	160 $^{\circ}$F
* water quality (max. particulate size)	0.1 mm or 100 micron

As required by the Naval Postgraduate School in an effort to increase water conservation, the water system must also be a closed system with minimal need for system flushing and replenishment. The dynamometer manufacturer also specifies various water quality requirements [Ref. 5: p. 1.10]. However, the water quality provided by the California American Water Company [8] more than satisfies these requirements and no water additives to maintain water quality were deemed necessary. An annual system flush will also adequately maintain the required water quality for parameters such as hardness and pH.

2. System Design

A 1,040 gallon steel water tank was installed along with two water supply pumps, a radiator type heat exchanger, and the required supply and return piping (2 IN diameter) from the auxiliary machinery equipment pad to the test cell. The first step of the water

system design was to determine if the equipment installed by the building contractor was adequate to support gas turbine and dynamometer operations.

a. Water Storage Tank

A cylindrical, steel water storage tank is located on the auxiliary machinery equipment pad. The tank, which is 12 FT long and 4 FT in diameter, has a capacity of 1,040 gallons. The tank has a 3 inch diameter suction line which is reduced to a 2 inch diameter pipe prior to entering the filter. Within the suction line is a 3 inch fill connection. A 1 inch diameter drain line with a 1 inch butterfly valve (CW-13) is also attached at the base for draining. A 100 PSIG relief valve and a vent valve are also included to prevent over pressurization and back pressure conditions. A 2 inch suction valve (CW-1) was added to the system piping in order to facilitate isolation of an added filtration unit. Cleaning of the filtration element requires isolation or draining of the water storage tank prior to opening the filtration unit.

b. Supply Filtration Unit

In order to meet the maximum particulate size of 0.1 mm or 100 micron, a filtration unit (50 micron) is installed in the 2 inch suction line prior to the supply pumps. The filtration unit, which is pictured in Figure 5.2, is installed in order to augment the 100 micron filter located at dyno power absorber inlet. An added filter is necessary to prevent rust and scale particles, which may dislodge from the sides of the steel tank and piping during operation, from clogging the installed dynamometer filter and reducing the flow of supply water to the power absorber. The filter also allows for system recirculation to remove particulate from the tank if the system has been secured for long periods. Supply

water is discharged from the filter through 2 inch piping and a 2 inch butterfly suction cut off valve (CW-2GT) into the inlet of the supply pump.

c. Supply Pumps

Since the maximum power rating for the T63-A-700 engine is 317 HP, a maximum water flow rate of 32 GPM is needed at a minimum supply pressure of 35 PSIG (81 FT H_2O). The two water supply pumps are centrifugal and are rated at 50 GPM at 125 FT H_2O head (54 PSIG). Using the rated flow rate of 50 GPM (0.1114 FT^3 /SEC) and using an average kinematic viscosity of water as 9.30E-6 FT^2 / SEC with a pipe diameter of 2 IN, a Reynolds number $\mathbf{Re_D} \sim 91{,}500$ is found. The piping from the supply pumps to the dynamometer are schedule 40 steel with a nominal roughness to diameter ratio of 0.0009. From the Moody Diagram a friction coefficient, $\mathbf{f} = 0.02$ is determined. The head losses (h_f) can be calculated from the equation:

$$h_f = \mathbf{f}\ (L/D)\ (V^2/2g) \qquad (5.1)$$

where (L/D) is the pipe length to diameter ratio and V is the fluid velocity. The piping run from the supply pumps to the dynamometer is approximately 50 FT in length and has eight - 90 degree bends, two gate valves, and one angle lift check valve installed. The head loss factors K_1 (90 degree bend), K_2 (gate valve), and K_3 (angle check valve), were determined from tabulated sources [Ref. 9: p. 224-229] as 0.9, 0.19, and 5.0 respectively. The effective length, L_e was calculated from the equation:

$$L_e = K^*D\ /\ \mathbf{f} \qquad (5.2)$$

where $K = 8K_1 + 2K_2 + K_3 = 8(0.9) + 2(0.19) + (5.0) = 12.6$. Thus, the effective length, L_e is found to be 105 FT. The total head loss from the supply pumps to dynamometer is then calculated from Eq (5.1):

$$h_f = 0.02 * ((105 + 50)/(2/12)) *(5.1^2/(2*32.17)) = 7.6 \text{ FT } H_2O \text{ or } 3.3 \text{ PSIG}$$

From the preceding head loss calculation, one can see that the head losses are insignificant and the centrifugal water supply pumps satisfy both the flow and pressure requirements for safe dynamometer operations.

The supply pumps are configured such that either pump can be used for the Diesel or gas turbine cell in a series or a parallel configuration as shown in Figure 5.1. However, the normal configuration for gas turbine dynamometer operation will be one supply pump in operation with the other supply pump secured with the cross connect valve (CW-5) closed.

d. Dynamometer Power Absorption Unit

Water discharged from the supply pump flows through a 2 inch angle swing check valve (CW-3GT) and a 2 inch butterfly cut off valve (CW-4GT) into the gas turbine test cell via the piping trench at the base of test cell wall. Located just inside of the test cell, a dyno bypass line, a system unloader (CW-8GT) and a dyno supply line are configured in parallel. The dyno bypass valve (CW-7GT), which is closed during dynamometer operation, allows for system recirculation prior to placing the water system into service.

Supply water enters the dynamometer sump tank, which is discussed Chapter III.B.6, through a float control valve into the segregated supply side of the sump

tank. The float control valve utilizes a float and arm assembly to secure the water supply to the tank and prevent overflow during low demand conditions. A 1 inch boost line branches off the supply line just prior to the float control valve. This boost line provides a pressurized water supply to the power absorber during periods of rapidly increasing gas turbine loading conditions; a feature needed to prevent engine overspeeds during conditions of high water flow and low supply pressure. The design requirement for the water supply pressure to be a minimum of 35 PSIG is for support of the boost feature. The supply water in the dyno sump tank is open to the atmosphere and is drawn into the power absorption unit by the water brake impeller through a 100 micron filter. The dyno power absorber dissipates the gas turbine output power by transforming the output power into a change in enthalpy. The elevated water temperature caused by the increase in enthalpy is carried away from the power absorber by the water as it is discharged to the return side of the segregated sump tank (power = water mass flow rate * change in enthalpy across the power absorber).

e. Return Pump

Since the water is discharged from the power absorber to an open sump tank, a return pump is required to pump the fluid from the dyno through the heat exchanger and ultimately back to the storage tank. In order to determine the size of the return pump, simple head loss calculations were done. The piping run from the dynamometer to the storage tank is approximately 70 FT with twenty-one 90 degree bends, three gate valves, one TEE, a heat exchanger, and one rapid expansion into the tank. The head loss factors K_1 (90 degree bend), K_2 (gate valve), and K_3 (TEE), were determined to be 0.9, 0.19, and 1.8 respectively. Therefore, $K = 21K_1 + 3K_2 + K_3 = 21(0.9) + 3(0.19) + 1.8 = 21.3$. From Eq 5.2, L_e was found to be 178 FT. The pressure loss across the heat

exchanger, as specified by the manufacturer is 0.3 PSIG (0.69 FT H_2O) at this flow rate. An elevation rise of 5 FT is also present because the piping discharges into the top of the tank. The head loss due to the rapid expansion entering the storage tank, h_e, is found from the equation:

$$h_e = (V_0 - V_e)^2 / 2g \qquad (5.3)$$

where $V_e = 0$. Thus, $h_e = (5.11)^2 / (2(32.17)) = 0.41$ FT H_2O.

The total head loss was estimated from Eq 5.1 as :

$h_f = 0.02 * ((178 + 70)/(2/12)) *(5.1^2/(2*32.17)) + 0.41 + 0.69 + 5 = 18.1$ FT H_2O or 7.9 PSIG.

When selecting the return pump, the main design consideration was choosing a pump with a larger designed flow rate than the supply pump. This is required to ensure that no condition may exist which will allow the dyno sump tank to overflow while the return pump is in operation. From these considerations a return pump rated at 75 GPM at 50 FT H_2O head was selected (1.5 times the capacity of the supply pumps). In order to eliminate the requirement for a foot valve, the selected return pump is also self priming to 12 FT H_2O and has an internal check valve to prevent backflow from the water storage tank.. The return pump, which is a centrifugal pump, discharges the heated water through a 2 inch globe valve (CW-9GT). A globe valve is used instead of a butterfly gate valve in order to provide a means of throttling the return pump during low engine loading conditions. Since the possibility exists that at low load demands on the dyno waterbrake may occur which produce low effluent water flows, a centrifugal pump vice a positive

displacement pump was chosen. A centrifugal pump is more durable in such an environment. A photograph of the return pump is presented as Figure 5.3.

f. Heat Exchanger

A principal design consideration of the water system is the capability of the system to reject the heat added to the system by the power absorption unit. As specified by Superflow Corporation [Ref. 5: p. 1.9], the water discharge temperature from the power absorption must not exceed 160 °F. At temperatures greater than 160 °F, the power absorption capability of the water brake may become erratic and produce an engine overspeed. The capacity factor (overall heat transfer coefficient) of the heat exchanger is 1.30 HP/°F (55 BTU/MIN °F) which corresponds to a heat removal rate of 130 HP at maximum water temperature when considering an ambient air temperature of 60 °F. When one considers that the maximum power rating of the T63-A-700 gas turbine engine is 317 HP, it is evident that the run time for the gas turbine engine at high loading will be limited by the cooling capacity of the heat exchanger and the thermal inertia of the system. Since the primary use of the gas turbine test cell is student laboratory instruction, system run times of approximately two hours are desired in order to allow sufficient time for data collection at various power ratings. Since the requirement for multiple laboratory trials also exists, the water cooling system must have the capability to cool the water temperature to near ambient temperatures within two hours after securing the gas turbine. This capability would allow two laboratory experiments to be run in a normal workday. With the present configuration, a system run time for the gas turbine engine ranges from approximately 90 minutes at 200 HP to approximately 45 minutes at 300 HP which is less than the time required to complete the necessary data collection for meaningful engine performance

evaluation. In an effort to overcome this shortcoming, an alternative solution to the present heat exchanger configuration is investigated and presented in Chapter VI.

After the water temperature is reduced in the heat exchanger, the water is returned to the storage tank through a return line located at the top of the tank. A 100 PSIG relief valve (CW-14) is also installed in the piping above the tank which provides protection from system and tank over pressurization.

3. Water System Alignment and Operation

The water supply system should be recirculated for approximately 40 minutes prior to placing system into service if the system has been idle for more than 30 days. The 40 minute recirculation time constitutes two passes of the water supply through the 50 micron supply filter. This will ensure sufficient filtering of sediment and rust particles from the tank. Although the capability exists to run both supply pumps in a parallel or series configuration, the recommended configuration is one supply pump aligned for operation with the second secured with the cross connect (CW-5) closed. One supply pump is more than adequate in capacity to provide a sufficient water supply to the dynamometer. A complete description of the water system alignment is contained in the Standard Operational Procedure (SOP MLOP) presented in Chapter VII.

C. FUEL OIL SERVICE SYSTEM

The function of the fuel oil service system, which is shown in Figure 5.4, is to provide a continuous fuel supply of Diesel Fuel #2 to the T63-A-700 gas turbine engine. The entire fuel oil service system is comprised of three subsystems: the auxiliary support piping and equipment, the dynamometer fuel system, and the gas turbine fuel system.

Since the fuel oil service system must service both the Diesel and gas turbine test cells, the fuel selected must be compatible with both the Diesel and gas turbine engines. After consultation with technical representatives from both Detroit Diesel and Allison Gas Turbine [6], it was decided that Diesel Fuel #2 would be used as the common fuel for both engines. Although JP-4 is the primary fuel specified for use in the gas turbine engine, Diesel Fuel #2 is an acceptable alternative since the gas turbine engine will be subjected to relatively low operating hours (less than 100 hours) and in ambient conditions greater than 40 °F. Using Diesel Fuel #2 will, however, decrease hot section durability. If the gas turbine test cell is in operation during periods when the ambient temperature is less than 50 °F, the fuel system should be placed into recirculation mode for 30 minutes prior to gas turbine light off. During cold conditions, this practice will prevent paraffin separation that may prevent good fuel atomization in the combustion chamber.

1. Design Criterion

The principal design criterion is to provide fuel to the T63-A-700 engine at a minimum flow rate of 0.5 GPM and a pressure of 6 to 10 PSIG. This flow requirement is derived from the specific fuel consumption, SFC of the engine at maximum power. At 317 HP, the SFC is 0.697 LB/HP-HR which corresponds to approximately 0.45 GPM. Since the dynamometer was principally designed for internal combustion engines, the pressure limitations are imposed by the capacity of the installed dynamometer fuel system components. Even though the gas turbine engine utilizes its own duel element fuel pump, bypassing of the dynamometer fuel system will disable the fuel flow measurement and monitoring capability of the dynamometer control system.

2. System Design

During the construction of the Mechanical Engineering Building a fuel storage tank was installed on the auxiliary machinery equipment pad along with two supply pumps and the associated 3/4 inch supply and return piping to the test cell. The first phase in the design of the fuel system was to determine the compatibility of the existing equipment, provided by the contractor during the construction of the building, with the design parameters needed for safe test cell operation.

a. Fuel Storage Tank

The above ground, concrete fuel oil storage tank, which has a 500 gallon capacity, is 11 feet long, 4 feet wide and 3.5 feet high. The tank has a vent, a sampling tube, a leak detector tube, as well as, the standard fill and drainage connections.

b. Fuel Supply Pumps

The two fuel supply pumps, which are piped in a parallel configuration, take suction from the fuel oil storage tank through a common 3/4 inch swing check valve (FOS-1) and their respective 3/4 inch butterfly cutoff valve (FOS-2GT). The fuel supply pumps are positive displacement gear type pumps with an internal relief. The pumps are rated at 3 GPM at 125 FT H_2O head (54 PSIG). A 3/4 inch butterfly cross connect (FOS-3) provides the capability of using either supply pump for service to both the Diesel and gas turbine test cells. Prior to entering the test cell, the fuel flows through another 3/4 swing check valve (FOS-4GT) and a butterfly cut off valve (FOS-5GT). Just inside the cell

another 3/4 inch butterfly cut off valve (FOS-6GT) is located in the piping trench to provide double valve protection for a flammable liquid.

c. Flow Regulator (55 to 12 PSIG)

The maximum supply pressure to the dynamometer fuel system is 12 PSIG. The maximum pressure limitation is imposed by an internal relief valve in the dynamometer fuel system which is set at 12 PSIG. This relief valve is not of rigorous construction and is not designed to be continually actuated as would occur when the system supply pumps, which are rated at 125 FT head (54 PSIG), are placed in operation. In order to avoid premature failure of the dynamometer fuel system relief valve, a flow regulator (FOS-7GT) is piped into the system prior to the dynamometer fuel supply connection. This flow regulator is adjustable from 0-25 PSIG with a minimum flow coefficient, CV=1.1. The flow regulator, which is adjustable via a manual knob on the valve body, also has 1/4 inch gauge ports on the inlet and discharge connections for monitoring. When adjusted for discharge pressures of less than 12 PSIG, the flow regulator will also restrict the supply flow rate to approximately 1 GPM. The positive displacement, gear driven supply pumps have an internal relief which will prevent adverse pump stress and wear due to back pressure induced by the flow regulator.

d. Adjustable Relief Valve

In order to provide additional protection from over pressurizing the dynamometer fuel system, an adjustable relief valve is positioned at the discharge of the flow regulator. The relief will be set at 12 PSIG and will bleed fuel to the return line in the

event that the flow regulator should fail. A picture of the flow regulator and relief valve are shown in Figure 5.5.

e. Fuel Filters

The Diesel fuel, that has been reduced to approximately 1 GPM at 6-10 PSIG, is passed through two FRAM fuel filters which are of 10 and 5 micron respectively. These additional fuel filters are installed to provide fuel filtering prior to entering the dynamometer and gas turbine fuel system. These added fuel filters are necessary because of the difficulty of changing the gas turbine 10 micron paper filter. The external fuel filters also provide the capability of filtering, to an acceptable fuel oil quality prior to engine light off by utilizing the fuel recirculation bypass valve (FOS-9GT).

f. Fuel Solenoid Operated Trip Valve

The primary means for emergency fuel shut off is the fuel solenoid trip valve (FOS-10GT) located just prior to the engine fuel oil supply connection. The solenoid is energized open by 12 VDC power from the storage batteries. Therefore, the fuel solenoid valve is energized open when the dyno fuel pump is turned on and closed when the dyno fuel pump is secured. This arrangement provides for positive fuel shut off by simply securing the dyno fuel pump or the dyno control console and also provides the additional safety feature by securing fuel to the gas turbine in the event electrical power loss occurs within the building or system.

g. Return Line

A discharge connection is located on the dynamometer fuel system that allows for discharge of unused fuel through the relief valve on the accumulator. This discharge connection is attached to a 3/4 inch return line which exits the test cell and returns to the storage tank. This return line is also used during fuel system recirculation via fuel recirculation bypass valve as was discussed in Chapter V.2.e. A complete equipment listing for the fuel system is contained in Appendix C.

3. Fuel System Alignment and Operation

The normal configuration for fuel system alignment to the gas turbine test cell is one supply pump aligned for operation with the other supply pump secured and the cross connect (FOS-3) closed. The flow regulator and adjustable relief are to be set at 10 and 12 PSIG respectively. The actual setting of the flow regulator may vary after system testing. A complete description of the fuel system alignment for engine light off and fuel oil system recirculation is contained in the Master Lightoff Procedure (MLOP) and the Fuel Oil System Recirculation Procedure (FOSRP) in Chapter VII.

D. AIR SUPPLY AND VENTILATION SYSTEM

The support function of the air supply and ventilation system is two-fold. Firstly, the system must provide an adequate engine air supply with a pressure drop within OEM limits which will support gas turbine operations. Back pressure due to filtration and ducting must be minimized. Secondly, the test cell must have sufficient exhaust ventilation

in order to prevent a temperature increase within the cell of more than 5.0 °F. This can be accomplished if there is a sufficient secondary air or "through flow" from the intakes through the module and out of the exhaust ducting.

1. Design Objectives

The principal design objective for the air supply and ventilation is to provide a minimum air flow of 3,000 SCFM to the gas turbine compressor inlet. At maximum power, the air flow rate through the gas turbine engine is 2,600 SCFM at 60 °F. [Ref. 1: p. 4.20]

As recommended by the dynamometer manufacturer, the supply and exhaust system should provide an air flow through the cell which produces a cell air exchange rate of 8 to 10 times per minute. [Ref. 5: p. 1.10] An air exchange rate of this magnitude will prevent unpredictable fluctuations in space temperatures that may affect the performance of instrumentation equipment. This design objective, however, has been determined to be unachievable from flow rate estimates. Additional research is being conducted using exhaust eductors to optimize secondary air flow, and cost estimates are being investigated for an additional electrical cooling fan to be installed in the building exhaust ducting. After sufficient engine testing and test cell temperature measurement, a decision will be made.

2. System Design

a. Supply Ducting

The air supply ducting provided by the contractors during construction of the Mechanical Engineering Building positioned the air intakes above the auxiliary machinery equipment pad external to the test cell. Outside air enters the supply ducting through louvers located on the building exterior as shown in Figure 4.4. Just inside the louvers is a 1/2 inch mesh foreign object debris screen and shutters. The shutters are a fire prevention and control device which automatically close in the event of a fire. The shutters are manually spring loaded open and are released if fire detectors sense a fire thereby sealing off air supply to the cell. This feature, however, was not completed properly by the building contractor and is being added to the contractor discrepancy package. After entering the shutters, the supply air travels approximately 5 feet horizontally through air intake silencers above the gas turbine test cell. The supply air is then turned 90 degrees downward through a 48 inch X 48 inch opening in the test cell ceiling.

In order to provide the capability to direct air flow, as well as, the ability to close-off the intake when the cell is not operational, adjustable shutters are mounted over the opening which are mechanically linked to an electrical shutter motor. The shutter motors are powered from a 230 VAC breaker located near the control console in the remote breaker panel .

Positioned above the ceiling shutters are four - 24 inch X 24 inch high performance air filters which provide filtration of particles above three microns at 95% efficiency. A minimal pressure drop of less than 1 inch of water is expected when the filters are in a clean condition.

b. Inlet Plenum

The gas turbine engine compressor inlet is attached to an inlet plenum chamber which is fabricated from 1/4 inch clear Plexiglas and aluminum supports. The plenum is made of clear Plexiglas in order to allow observation of the air flow profile into the compressor. On the intake side of the plenum, two air flow turbines are mounted which are used to measure the air flow rate into the compressor. Since each air turbine is rated to measure only 1,200 SCFM, the turbines are wired in parallel which increases the measurement range to 2,400 SCFM. Although the maximum air flow rate of the gas turbine is approximately 2,600 SCFM, this range is sufficient for most gas turbine operations. The manufacturer suggests that each air flow turbine has the capability to measure air flows of up to 1,500 SCFM each without altering their calibration.

Inside the plenum chamber, a system of screens and baffle plates are used to direct the air flow into the compressor inlet. These screens and plates are used to break up any vortices or flow disturbances produced by the flow turbines which may cause a compressor stall. Once through the flow turbines, the supply air encounters a 20-mesh screen followed by an 18-mesh screen. Next, the air flows through an aluminum baffle plate with 1 inch holes followed by another plate with 1/2 inch holes. Both plates are 48% open. From the last baffle plate the air exits the inlet plenum through a calibrated compressor bellmouth into the inlet guide vanes of the compressor.

c. Exhaust Ducting

In order to achieve the aforementioned criterion of a high air exchange rate, an eductor system is being designed as part of another thesis project. This ducting will be

fabricated from 316 stainless steel and will attach to the exhaust ducts on the gas turbine engine. A separate 8 inch vertical duct will be used for each of the dual exhaust ducts from the engine and will direct the exhaust upward toward the 36 inch by 36 inch exhaust opening in the test cell ceiling. The nozzles will be sized and fitted approximately 12 inches below this opening in order to produce the desired air eductor effect. The eductor nozzles will be both variable in height and in diameter for experimentation and flow optimization.

Once the exhaust air enters the ceiling opening, it is turned 90 degrees and directed horizontally above the ceiling to the exterior of the building. After exiting the building, the flow is again turned 90 degrees upward by circular exhaust ducting. This ducting, which runs up the side of the building to the roof where it is capped, is also made of 304 stainless steel. A deflector shield will be installed along with exhaust flow measuring devices for mass flow rate and exhaust gas temperature. The exhaust uptakes are pictured in Figure 4.5.

d. Auxiliary Ventilation System

As part of the building construction, a 800 SCFM supply fan and ducting is installed on the intake side of the cell. Also included is a 800 SCFM exhaust fan at the exhaust side of the cell. This system can be used to ventilate the test cell when the gas turbine engine is secured. The supply and exhaust fans are controlled by a thermostat switch just outside the entrance doors to the test cell.

E. LUBE OIL STORAGE AND CONDITIONING SYSTEM

The T63-A-700 gas turbine engine utilizes a circulating dry sump system with supply and scavenge elements enclosed inside the engine's accessory gear box. Therefore,

the support function of the lubrication storage and conditioning system is to provide a means of storing and cooling of the MIL-L-23699 lubricating oil. A more detailed discussion of the internal components within the engine lubrication system is presented in Chapter II, Section C.

1. Design Criteria

There are three main design requirements of the lubrication oil storage and conditioning system. The system must have the capacity to store a minimum of six quarts of lubricating oil. Secondly, the system must be able to maintain the system oil temperature below 225 °F. Lastly, the dynamometer test system must be successfully instrumented for proper monitoring of system pressure and temperature.

2. System Design

The design philosophy for the lubrication system was simple; utilize existing airframe components and make the necessary modifications for use with the dynamometer test system. A complete listing of these parts is contained in Appendix C.

a. Storage Tank

The oil storage tank, which constructed from sheet metal, is mounted near the dynamometer test stand. The tank has a 5 gallon capacity and connections for fill, supply, and return. A vented fill cap is also provided to prevent system or tank over pressurization. The tank will have a dipstick installed with a low mark placed at the 4 gallon level.

b. External System Piping

The engine's accessory gearbox provides connections for both the supply and return lines. A supply line, which is connected from the storage tank to the front of the accessory gearbox, transports supply oil from the storage tank to the engine supply elements. A discharge line, connected to the front of the accessory gearbox, returns the discharged oil back to the storage tank via an oil cooler. The supply and pressure sensing piping is made form 3/8 inch Teflon flexible hose with a 304 stainless steel overbraid. The discharge piping is made of the same material and is 1/2 inch diameter.

c. Oil Cooler

The oil cooler is a radiator, fin type heat exchanger which utilizes forced air from a gear driven fan to cool the lubrication oil. In the airframe, the gear driven fan is powered by shafting from the tail rotor transmission assembly. This configuration is not possible since the tail rotor connection is used for the main drive shafting from the engine to the dynamometer power absorber. In order to overcome this problem, an electric fan will be mounted behind the oil cooler for increased cooling effectiveness in order to provide the required forced air flow through the fin assembly.

d. Oil Pressure and Temperature Monitoring System

The Superflow dynamometer test system provides the capability to monitor system oil pressure, oil supply temperature, and oil discharge temperature. Oil pressure

monitoring is accomplished by the dynamometer test system via a sensing line between the pressure connection on the front of the accessory gearbox and the test stand instrumentation rack. From the instrumentation rack, another sensing line routes fluid pressure to a mechanical gauge on the dynamometer control console. The mechanical gauge has range of 0-160 PSIG which is sufficient to monitor normal system pressure (90-110 PSIG). However, the low oil pressure warning light, which is presently set at 15 PSIG must be reset at 50 PSIG; the minimum safe operating pressure for the engine. [Ref. 1: p. 1-4A] An emergency trip device will be added to the system which will secure power to the fuel solenoid trip valves if the oil pressure drops below 50 PSIG after the engine reaches idle speed. This additional safety feature, which is to be added as part of the instrumentation package, will provide an automated quick response to a low oil pressure condition and prevent an irreparable engine failure.

The dynamometer control system provides two thermocouples which provide the capability of measuring oil supply and discharge temperatures. A readout of the oil temperatures may be read from on the left most analog meter by selection of either OIL IN or OIL OUT on the TEMPERATURE METER knob. Since the maximum design operating oil temperature is 225 °F, the meter scale, which is 0-300 °F, provides the necessary range for proper monitoring of the system oil temperatures.

F. ELECTRICAL SYSTEM

The support function for the electrical system is to provide 230 and 115 VAC single phase power, as well as, 24 and 12 VDC power to the auxiliary support equipment, dynamometer control console, dynamometer engine stand, and the T63-A-700 gas turbine electrical system.

As part of the construction the Mechanical Engineering Building, 230 and 115 VAC are installed in the gas turbine test cell. A Westinghouse series distribution panel is located on the auxiliary machinery equipment pad as shown in Figure 5.6. Initially, the distribution panel contained local breaker motor control boxes for the fuel oil supply pumps, lubrication oil supply pumps, and the cooling system heat exchangers. Two additional breaker motor control boxes have been added due to the addition of cooling water return pumps for both the Diesel and gas turbine test cells.

As discussed above, the essential alternating current power supply system was provided for the gas turbine test cell during building construction. However, the required direct current power supply source and distribution were not included. The remainder of this chapter is devoted to a discussion of the direct current power distribution design, as well as, the modifications for remote operation of the auxiliary machinery equipment from the dynamometer control console operating area.

1. Design Criteria

The design objectives of the electrical system are two-fold. Firstly, a suitable direct current power distribution is required to support the T63-A-700 electrical system and the instrumentation and support equipment on the dynamometer engine stand. Secondly, a centrally located power panel for the auxiliary support equipment requiring alternating current power is desired for straight-forward test cell operation.

2. System Design

The gas turbine engine, requires 24 VDC power to the engine starter / generator and exciter while the dynamometer engine stand utilizes 12 VDC power. However, both are

powered by two-12 Volt batteries wired in a series configuration. A complete equipment listing is contained in Appendix C.

a. Storage Batteries

Since the gas turbine engine starter / generator utilizes 24 VDC power, two-12 Volt (800 cold cranking AMP) automotive batteries are wired in a series configuration. The batteries are mounted on the dynamometer engine stand. A 20/2 AMP 12 Volt battery charger is also provided for battery charging.

b. Starter / Generator

The engine starter / generator is energized by depressing the STARTER push-button on the dynamometer control console. Depressing the push-button places the starter / generator relay, which is mounted on the dyno test stand, into the start configuration thereby allowing electric current to flow from the storage batteries to the starter / generator. After the gas generator (N1) reaches idle speed (30,000-32,000 RPM), the STARTER push-button is released and the starter generator relay returns to the generator configuration. When in this mode the generator recharges the storage batteries via a voltage regulator that is also mounted on the test stand. A complete description of the gas turbine electrical system is discussed in Chapter II, Section C.

c. 12 Volt Dynamometer Engine Stand Power Switch

In order to provide 12 VDC power to the dyno engine stand, fuel pump, as well as, the fuel oil shutoff solenoid, a 12 Volt relay switch is connected to one 12 Volt battery. When the FUEL PUMP switch on the dyno control is turned ON, the 12 Volt relay is closed and a 12 VDC current flows to the fuel pump and the solenoid operated fuel trip. The electrical power energizes the fuel oil shutoff solenoid valve open simultaneously with the starting of dyno fuel pump. The solenoid is wired in series with the fuel pump and can only be energized open when the fuel pump is turned on.

d. Fuel Oil Solenoid Operated Shutoff Valve

The fuel oil solenoid operated shutoff valve is an added safety feature which provides a more positive control of fuel flow to the gas turbine engine. By wiring the fuel trip such that it is electrically energized open when the dyno fuel pump is turned on, the fuel pump switch can be used as the primary means of casualty control. The first immediate action in the Emergency Shutdown Procedure (SOP ESP) contained in Chapter VII, is securing the dyno fuel pump.

e. Remote Breaker Panel

Although the alternating current electrical distribution provided by the building contractor was adequate to support test cell operations, the system was not configured for remote operation. Therefore, modifications to the power distribution were

deemed necessary to facilitate remote operation of all auxiliary machinery by a single operator.

In order to achieve this goal, a remote power panel is installed near the dyno control console. Remote breakers for the fuel oil supply pump, cooling water supply pump, heat exchanger, cooling water return pump, and intake shutter motor are contained within the panel. A spare breaker is also provided for system expansion. During system alignment prior to engine light off, the Master Light Off Procedure (MLOP) requires placing of the local breaker motor control box, which is located inside the distribution panel on the auxiliary equipment pad, into the AUTO position. Positioning of the three way (HAND-OFF-AUTO) switch in the AUTO position, passes breaker control to remote power panel. If the breaker is placed in the HAND position, the equipment motors may be started from the START-STOP switches in the auxiliary machinery pad's local power panel. This electrical distribution panel configuration allows versatility in system operation and in the performance of maintenance procedures.

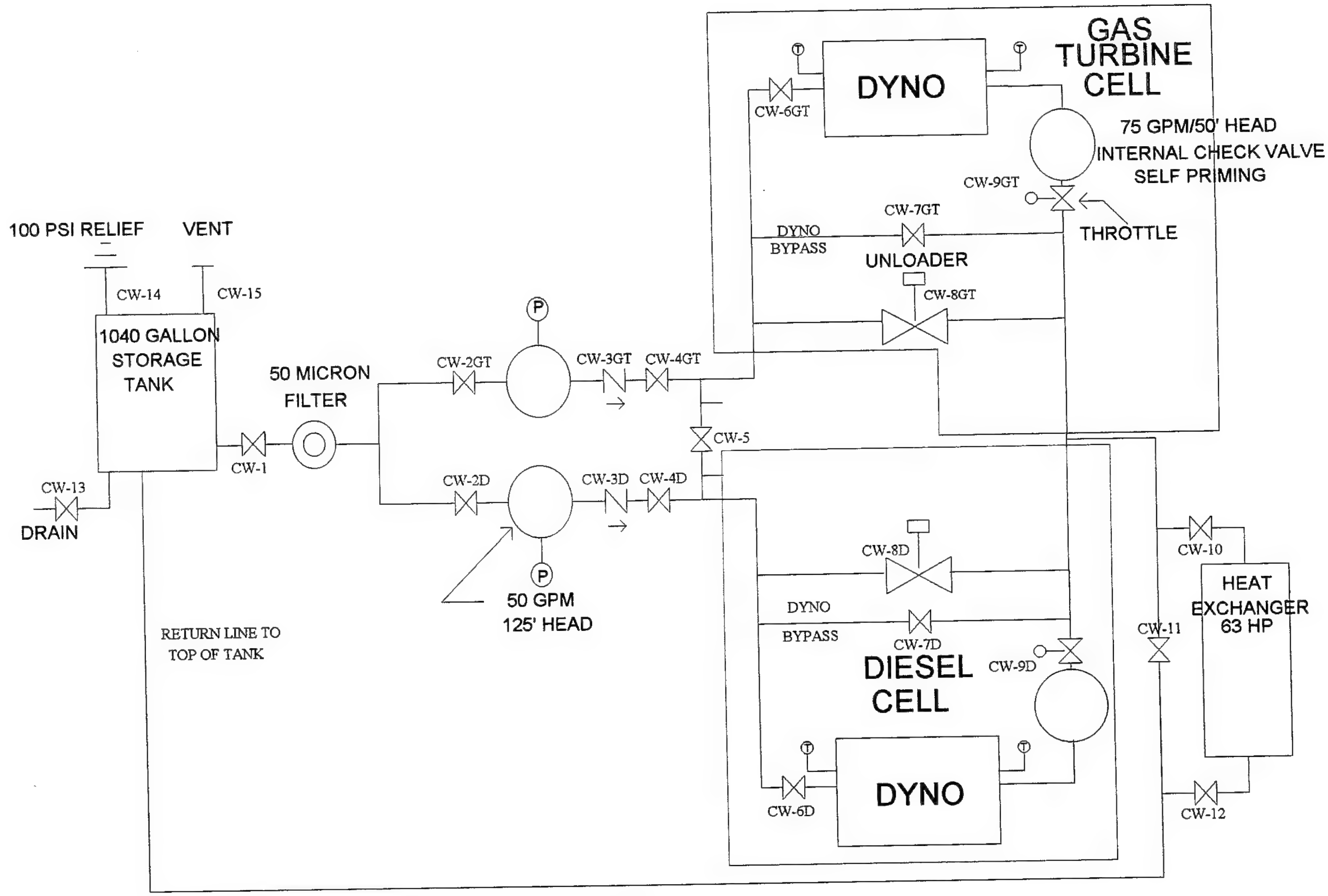


Figure 5.1. Dynamometer Water System Schematic

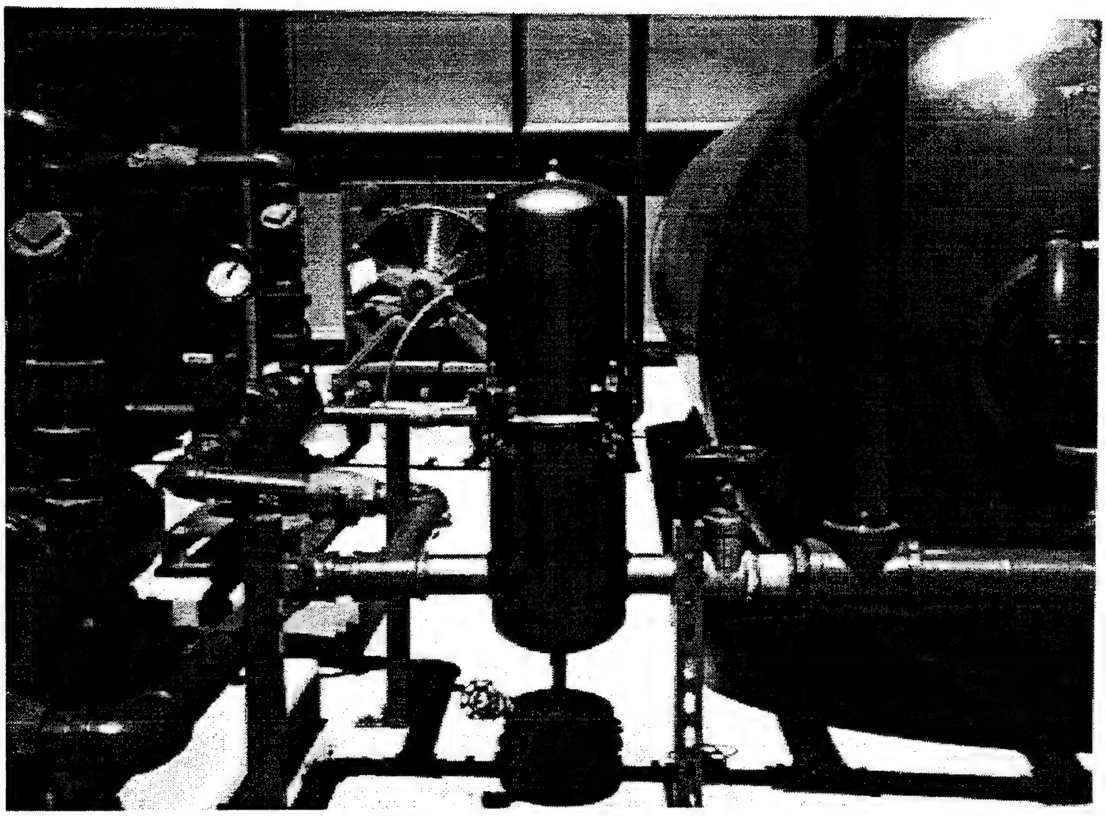


Figure 5.2. Cooling Water System Filtration Unit.

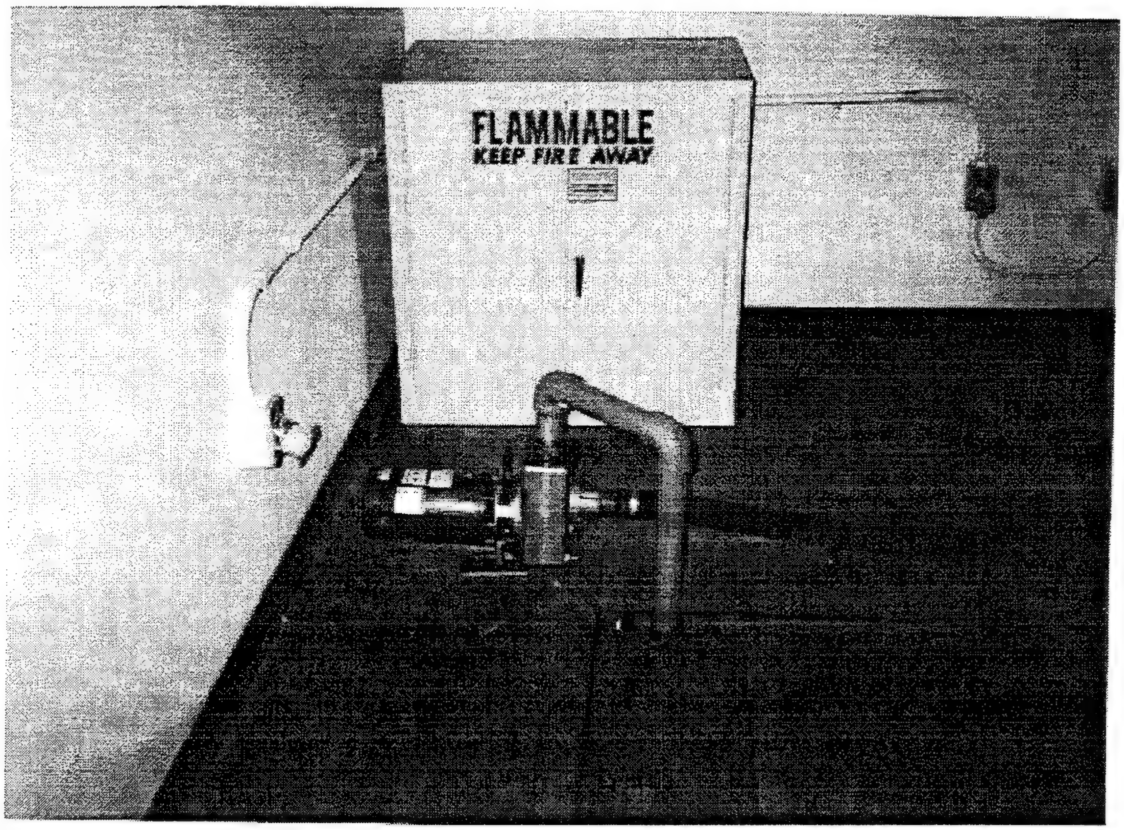


Figure 5.3. Cooling Water System Return Pump.

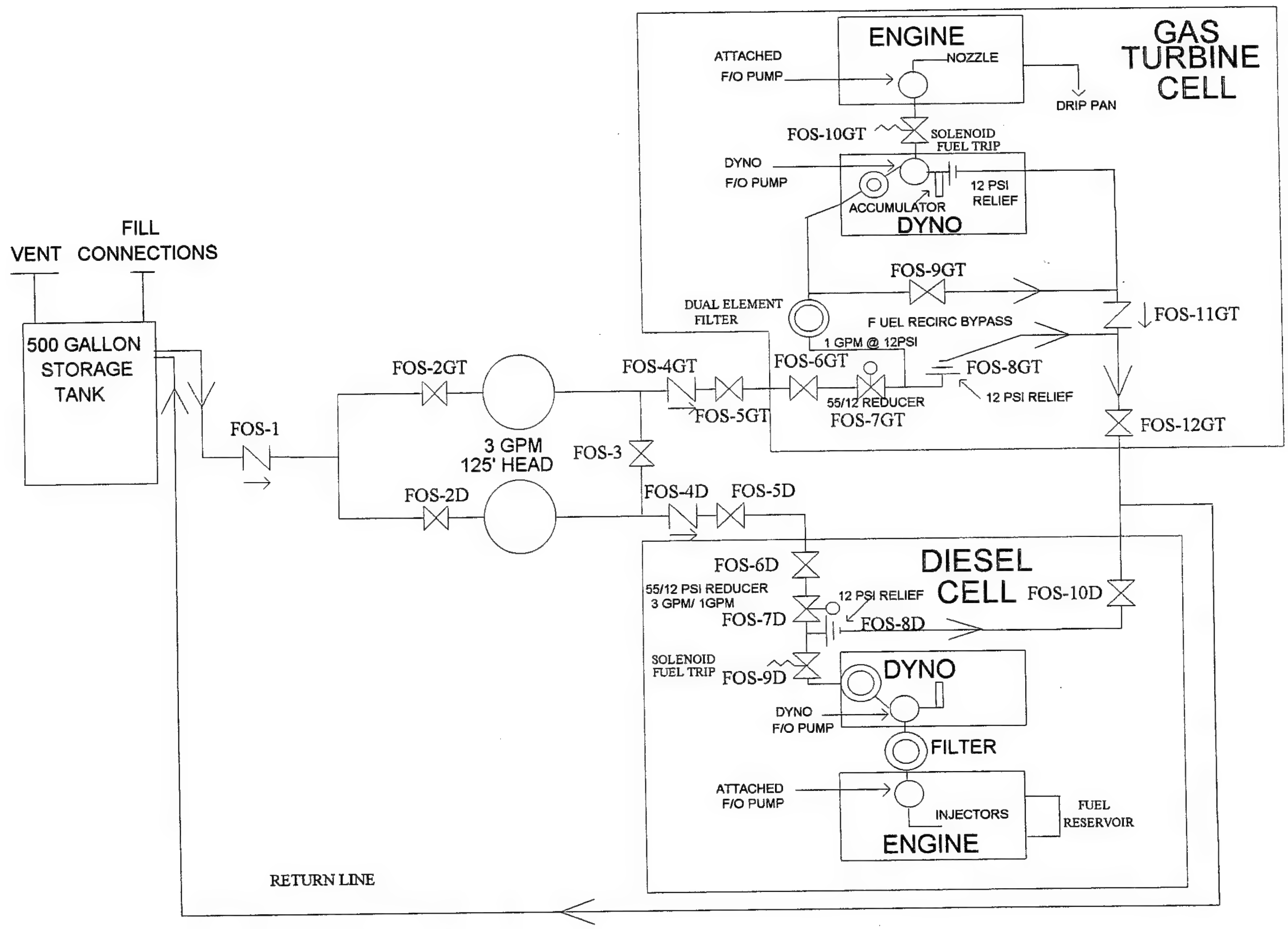


Figure 5.4. Fuel System Schematic

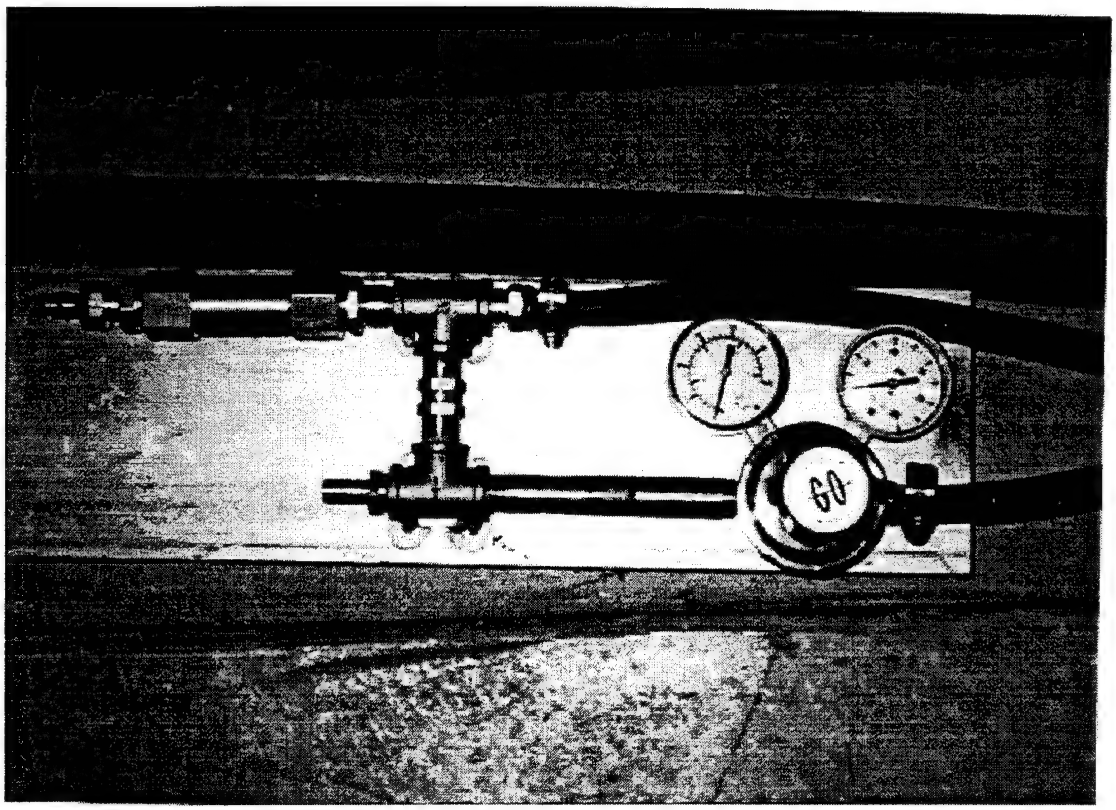


Figure 5.5. Flow Regulator and Relief Valve Assembly.

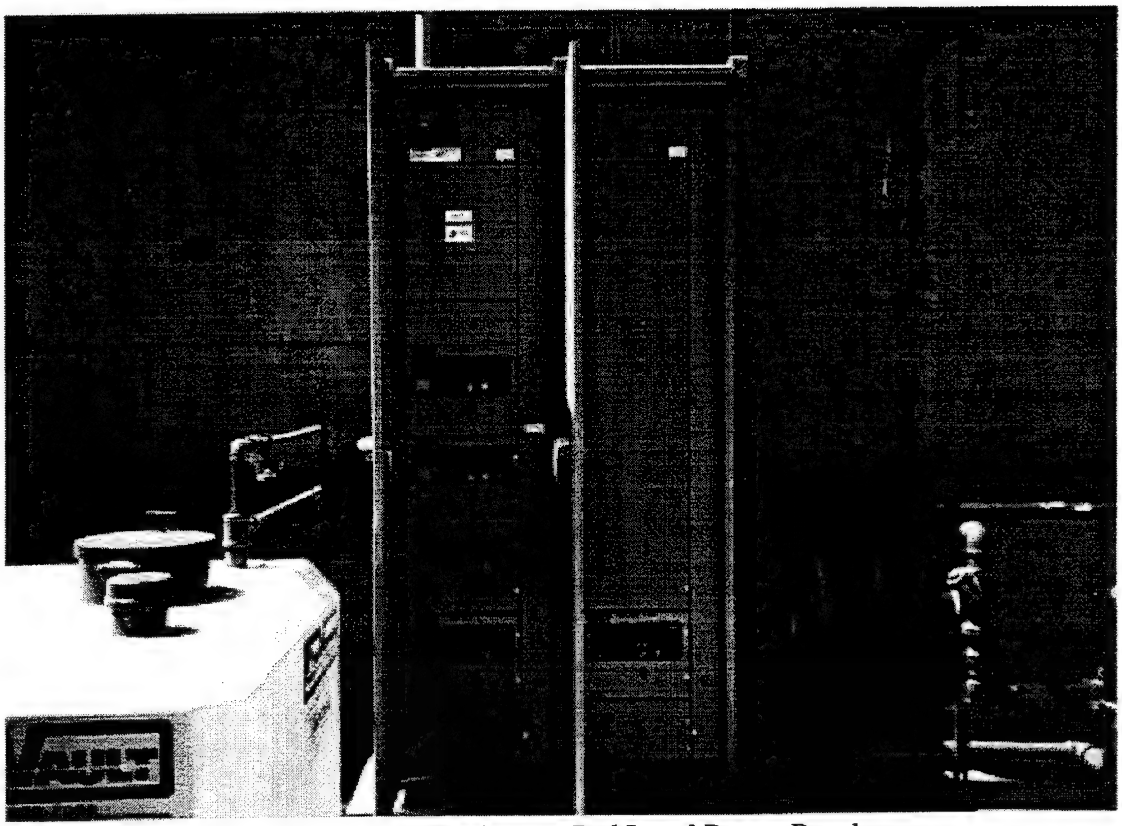


Figure 5.6. Auxiliary Machinery Equipment Pad Local Power Panel.

VI. HEAT EXCHANGER ALTERNATIVE STUDY

A. INTRODUCTION

The heat exchanger, as provided is inadequate because it does not provide sufficient cooling for the dynamometer water system (Figure 5.1) at steady state for loads greater than 150 HP. The heat exchanger, which is pictured in Figure 6.1, is an air cooled radiator type exchanger that provides forced air flow through a finned core.

In order to ensure safe operation, the dynamometer manufacturer specifies the maximum discharge water temperature from the power absorber / water brake must not exceed 160 °F. The capacity factor (overall heat transfer coefficient) of the heat exchanger is 1.30 HP/°F (55 BTU/MIN °F) which corresponds to a heat removal rate of 130 HP at maximum water temperature when considering an ambient air temperature of 60 °F. When one considers that the maximum power rating of the T63-A-700 gas turbine engine is 317 HP, it is evident that the run time for the gas turbine engine at high loading will be limited by the cooling capacity of the heat exchanger and the thermal inertia of the system. The purpose of this chapter is to report on a study that was conducted to assess the capabilities of the present cooling system and to investigate alternatives that will permit the system to operate in the steady state at full power. A transient analysis, utilizing a computer simulation, was used as a basis for the study.

B. ANALYSIS

1. Design Considerations

The principal design consideration for the dynamometer water cooling system is to provide sufficient system cooling for the dynamometer water brake. As specified by the dynamometer manufacturer [Ref. 5: p. 1.9], the water discharge temperature from the power absorption unit must not exceed 160 °F. At temperatures greater than 160 °F, the power absorption capability of the water brake may become erratic and produce an engine overspeed condition. The primary use of the gas turbine test cell is for student laboratory instruction. Run times of approximately two hours are anticipated. Since the requirement for multiple laboratory trials exists, the water cooling system must also have the capability to cool the water temperature to near ambient temperatures within two hours after securing the gas turbine. The heat exchanger must be able to sustain two hours of gas turbine run time at various power settings and be able to cool the water back to near ambient conditions within two hours after engine testing.

2. System Model

A simplified model of the water cooling system used in the transient analysis and computer simulation is shown in Figure 6.2. The pertinent system parameters, which are discussed in detail in Chapter V.A, utilized in this analysis are shown below:

* water storage tank capacity	1,040 gallons
* supply pump rating	50 GPM @ 125 FT head
* dyno discharge rating	1 GAL per 10 HP of load
* return pump rating	75 GPM @ 75 FT head
* heat exchanger capacity factor	1.30 HP/°F
* ambient air temperature	60 °F
* atmospheric pressure	15 PSIA
* tank diameter	4 FT
* tank length	12 FT

Since the objective of this analysis is to determine an approximate time dependent water temperature profile at the dynamometer power absorber discharge, the following simplifying assumptions are made:

* The power absorber dissipates the gas turbine output power by transforming the output power a change in enthalpy. The elevated water temperature caused by the increase in enthalpy is carried away from the power absorber by the water as it is discharged to the return side of the segregated sump tank by the water brake impeller.

* Since the tank and piping, which are located on the auxiliaries equipment pad external to the building, are mostly shaded, radiative heating of the water tank and system piping is neglected. Radiative cooling from the tank and external piping is also negligible (less than 1 HP).

* Free convection heat transfer from the water storage tank is modeled as cross-flow over a cylinder. End effects from the cylinder ends are also neglected for a conservative estimate.

3. Thermodynamic Analysis

The thermodynamic state points for the system analysis area are also shown in Figure 6.2. The MATLAB computer code utilized in the transient conduction analysis is contained in Appendix D.

State points 5-1

Since ambient temperature (T_{amb}) is assumed to be 60 °F, the initial water temperature in the tank (T_5) is also assumed to be 60 °F. The water enthalpy in the tank (h_5) is found from steam tables with the entering arguments of pressure (P_5) and temperature (T_5). Secondly, the enthalpy change across the supply pump is considered negligible over the pressure change from 15-70 PSIA for sub cooled water. Thus,

$$h_1 = h_5 \text{ and } T_1 = T_5. \tag{6.1}$$

State points 1-2

Since all energy dissipated by the power absorber is assumed to be transferred as heat to the water discharged by the water brake impeller,

$$Q_{12} = HP, \qquad (6.2)$$

where HP is the power output from the gas turbine engine.

The dyno enthalpy discharge (h_2) is calculated from the equation

$$h_2 = (Q_{12} + M_{dot} * h_1) / M_{dot}, \qquad (6.3)$$

where M_{dot} is the mass flow rate discharged by the power absorber. The temperature (T_2) is found by interpolation from steam tables using h_2 and P_2.

State points 2-3

Neglecting enthalpy and temperature changes across the return pump for sub cooled water yields

$$h_3 = h_2 \text{ and } T_3 = T_2. \qquad (6.4)$$

State points 3-4

The heat removed from the water system by the heat exchanger (Q_{34}) is calculated from

$$Q_{34} = C_f * (T_3 - T_{amb}), \qquad (6.5)$$

where C_f is the heat exchanger capacity factor. The heat exchanger discharge enthalpy is found from

$$h_4 = (M_{dot} * h_3 - Q_{34}) / M_{dot}. \qquad (6.6)$$

The temperature (T_4) is then found by interpolation from the steam tables as before.

State points 4-5

The water temperature change in the storage tank is a combination of two factors: the mixing of warm water from the heat exchanger with the water stored in the tank and heat removed by free convection from the tank to the surroundings. The mass fraction of water (frc) returned to the tank is found from

$$frc = V_{dot} * time / \boldsymbol{V}_{tank}, \qquad (6.7)$$

where V_{dot} is the volumetric flow rate and $\boldsymbol{V}_{tank}$ is the volume of the storage tank.

The bulk enthalpy of the tank (h_{tank}) is then found from

$$h_{tank} = [h_4 * frc + h_{pre4}] / (1 + frc) \qquad (6.8)$$

which may be simplified for frc ~ 0 to

$$h_{tank} = h_4 * frc + (1\text{-}frc) * h_{pre4}, \qquad (6.9)$$

where h_{pre4} is the tank enthalpy prior to mixing, in other words, the enthalpy from the prior time increment.

The free convection coefficient (H_{fc}) for a cylinder is approximated from the equation

$$H_{fc} = K_{air}/d * \{0.6 + (.387Ra_d{}^{1/6}) / [\,1 + (.559 / P_r)^{9/16}]^{8/27}\}^2, \quad (6.10)$$

where K_{air} is the thermoconductivity of air

d is the diameter of the storage tank

Ra_d is the dimensionless Rayleigh number

P_r is the dimensionless Prandtl number

The heat removed from the storage tank by free convection to the surroundings (Q_{45}) is governed by

$$Q_{45} = H_{fc} * \text{tank surface area} * (T_{tank} - T_{amb}). \quad (6.11)$$

The supply pump inlet enthalpy (h_5) is then calculated from

$$h_5 = (M_{dot} * h_{tank} - Q_{45}) / M_{dot}, \qquad (6.12)$$

and finally, T_5 is found by interpolation from the steam tables.

4. Computer Program Description

The computer program is written in MATLAB. The computer program utilizes a time marching scheme (one minute increments) and is essentially a repetition of the thermodynamic analysis described above for each step. The objectives of the computer code are to obtain graphs of water temperature at the dynamometer inlet, dynamometer discharge, and heat exchanger discharge verses time, as well as, engine power, heat removed by the heat exchanger, and heat removed by free convection verses time. The overall aim is to find a good estimate of the time required for the dyno discharge temperature to reach 160 °F at various engine loadings and a configuration which will allow for full power operation in the steady state.

5. Results from the Transient Analysis for the Existing Cooling System Configuration

Using the MATLAB computer code, graphs of water temperature verses time (Figures 6.3 - 6.5) were generated for gas turbine power ratings of 200, 250, and 300 HP respectively. Since the dynamometer power absorber water discharge temperature of 160 °F is the limiting parameter, the maximum system run time corresponds to this temperature. From these figures, one can see that the heat removal capacity of the present

configuration as installed is inadequate and does not provide for sufficient gas turbine engine run time to fulfill the student laboratory requirements. Also from these figures, it is observed that the system run time for the gas turbine engine ranges from approximately 90 minutes at 200 HP to approximately 45 minutes at 300 HP which is less than the time required to complete the necessary data collection for meaningful engine performance evaluation. The heat exchanger ineffectiveness at low temperature differences between the water temperature at the heat exchanger inlet and the ambient air temperature is apparent when observing the rapid temperature increase in the first minutes of gas turbine operation.

Figure 6.6 is a graph of heat rate verses time which shows the inability of the heat exchanger to match the heat addition by the dyno water brake. Also shown in this figure is the insignificant role that free convection plays in this configuration. The average free convection heat transfer coefficient is only the order of 0.5 to 0.9 BTU/ HR FT^2 ^oF (3.0 to 5.0 W/M^2 K). Figure 6.7 shows the time history of system cooling with the gas turbine secured after reaching the maximum dynamometer discharge temperature of 160 ^oF. The approximate temperature difference across the dynamometer is approximately 50 ^oF, thus the water tank temperature / dyno inlet temperature is approximately 110 ^oF at maximum dyno discharge temperature. From Figure 6.7, it is observed that system cooling time for the water supply to reach near ambient temperatures is over five hours which does not facilitate versatility in conducting more than one laboratory in a normal work day.

The above results clearly demonstrate the inability of the present cooling system configuration to satisfy the above design criteria. Therefore, the need for an alternative design of the water cooling system is warranted in order to provide the necessary versatility required in performing meaningful engine testing and research.

6. Results from the Transient Analysis for Cooling System Alternatives

The principal considerations in choosing an alternative for the present system are cost and the capability to successfully modify the system with minimal change to the present piping and pump configurations. As required by the Naval Postgraduate School in an effort to increase water conservation, the system must be a closed system. Therefore, alternatives such as an evaporative cooler and water make-up systems were not considered. The three alternatives considered in this study were the addition of a make-up pump to increase the mass flow rate through the heat exchanger, replacement of the present heat exchanger with one of higher capacity, and thirdly, addition of another water storage tank.

Since the water flow rate through the heat exchanger is controlled by the water discharged by the water brake impeller, which is rated at 1 GPM / 10 HP, the maximum flow rate through the heat exchanger is 30 GPM at 300 HP. The minimum allowable flow rate through the heat exchanger for optimum heat removal is 30 GPM. For all flow rates below this level, the capacity factor must be derated by 10% as was done in the simulations that produced Figures 6.3 - 6.6. In order to avoid derating the capacity factor, a make-up pump (5 GPM) as shown in Figure 6.8 is implemented to boost the flow rate for power ratings less than 300 HP. Figure 6.9 shows the results with the implementation of the make-up pump alternative. After comparing Figure 6.4 with Figure 6.9, one sees the addition of the make-up pump adds only approximately five minutes to the run time of the system. The problem with this solution is the loss of the high temperature gradient in the heat exchanger with the ambient air temperature caused by the mixing of the cooler water from the storage tank with the warmer water from the dyno discharge which results in an overall lower average temperature. Heat exchangers, as discussed in section 5, have

greater heat rejection capabilities at higher temperature differences. This factor diminishes the 10% increase in capacity offered by this alternative.

The second alternative considered was increasing the size of the heat exchanger and its capacity factor. Figure 6.10 shows the results of the simulation with a heat exchanger that has a capacity factor which is 1.5 times larger. This change does increase the run time to approximately 90 minutes but still does not achieve the design goal of two hours. However, increasing the capacity factor to 2.6 HP/°F (110 BTU/MIN °F), which is twice the capacity of the present heat exchanger, does meet the run time criterion as shown in Figures 6.11 and 6.12. From Figure 6.13, which is a graph of heat removal rate verses time, one sees the desired, near steady state, operating capability of the heat exchanger at the maximum temperature condition after three hours of gas turbine operation. The goal of successful heat exchanger design is the ability to reject as much heat as is added to the system when at the maximum temperature condition. Thus, the heat exchanger is operating efficiently at a maximum temperature gradient with the ambient air and the water temperature is no longer increasing. Figure 6.14 shows the capability of the heat exchanger to cool the system back to near ambient temperatures quickly, thereby permitting the operation of the laboratory again within two hours of securing the gas turbine from operation.

The last alternative considered was doubling the tank storage capacity from 1,040 gallons to 2,080 gallons. Doubling the tank size allows for approximately two hours of gas turbine operation at 250 HP which is an improvement but does not produce the desired results.

C. CONCLUSIONS AND RECOMMENDATIONS

Increasing this size of the heat exchanger from a 26D1Q to twice the capacity factor of 2.6 HP/ °F (110 BTU/MIN °F) as provided by the 66D2Q heat exchanger manufactured by Young Radiator, as shown in the specification sheet contained in Appendix D, can be accomplished with no piping changes for approximately $2,500. This change meets all the required design criteria, and the modification may be completed in less than one day after receipt of the heat exchanger. After considering the above factors, this study clearly shows that replacing the existing 26D1Q with the 66D2Q heat exchanger is both the simplest and most cost effective alternative to the present configuration. Therefore, it is recommended that the present 26D1Q be traded in for a 66D2Q at a net cost of $2,500 as quoted by [11].

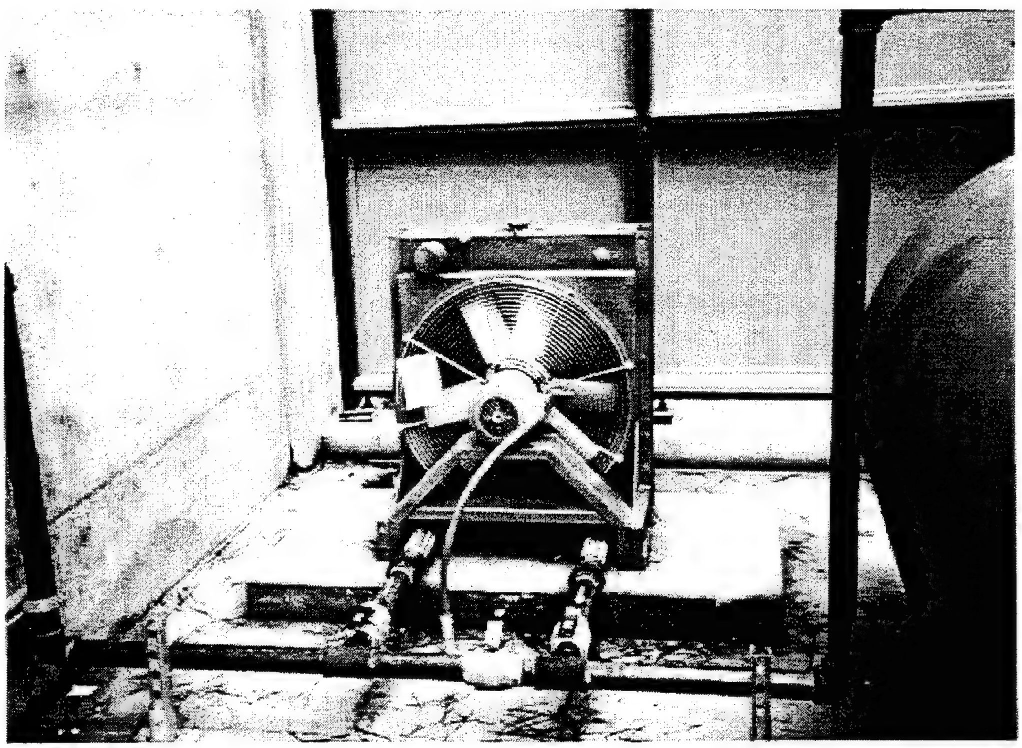


Figure 6.1. Photograph of Water System Heat Exchanger

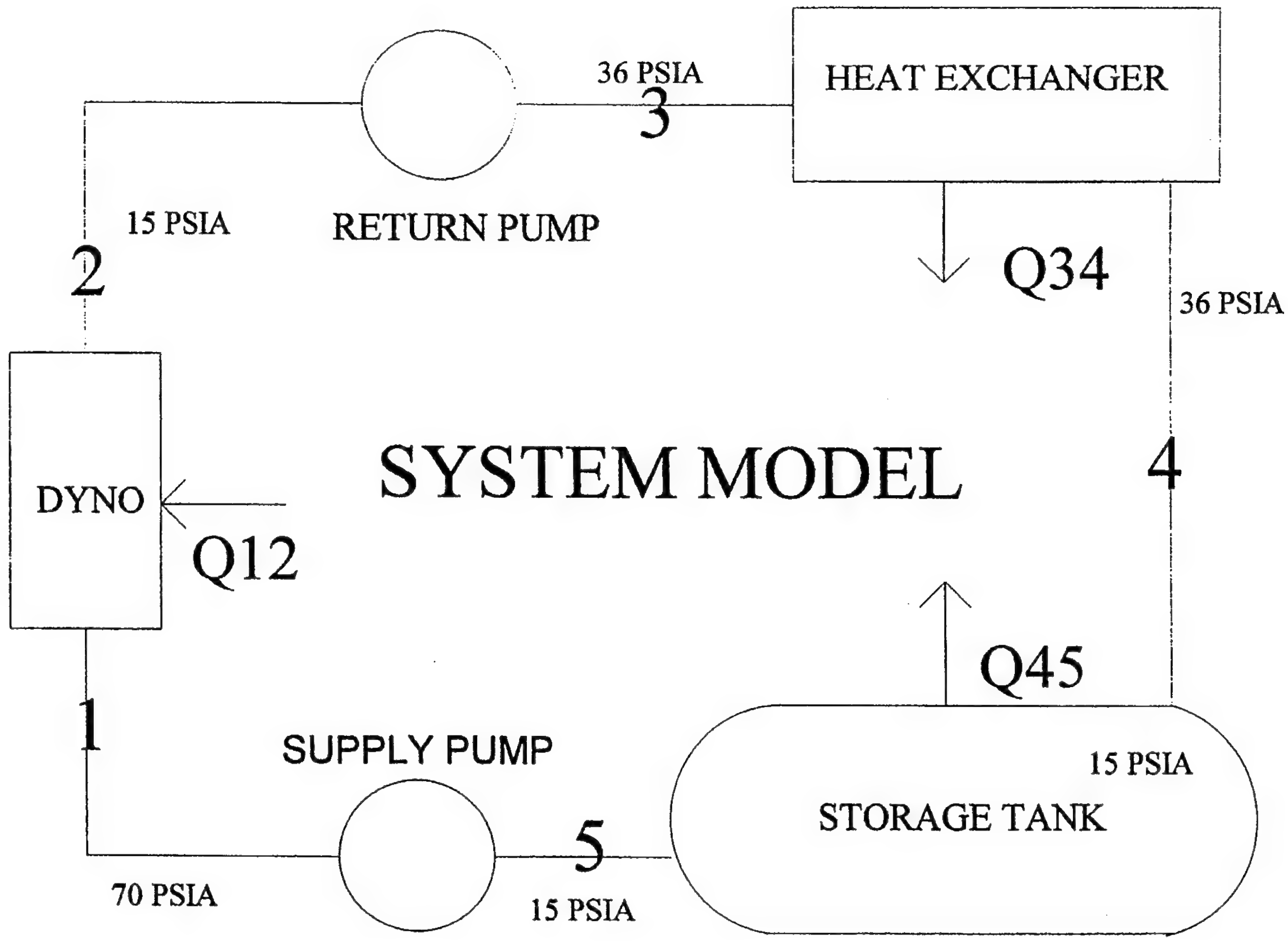


Figure 6.2. Thermodynamic System Model

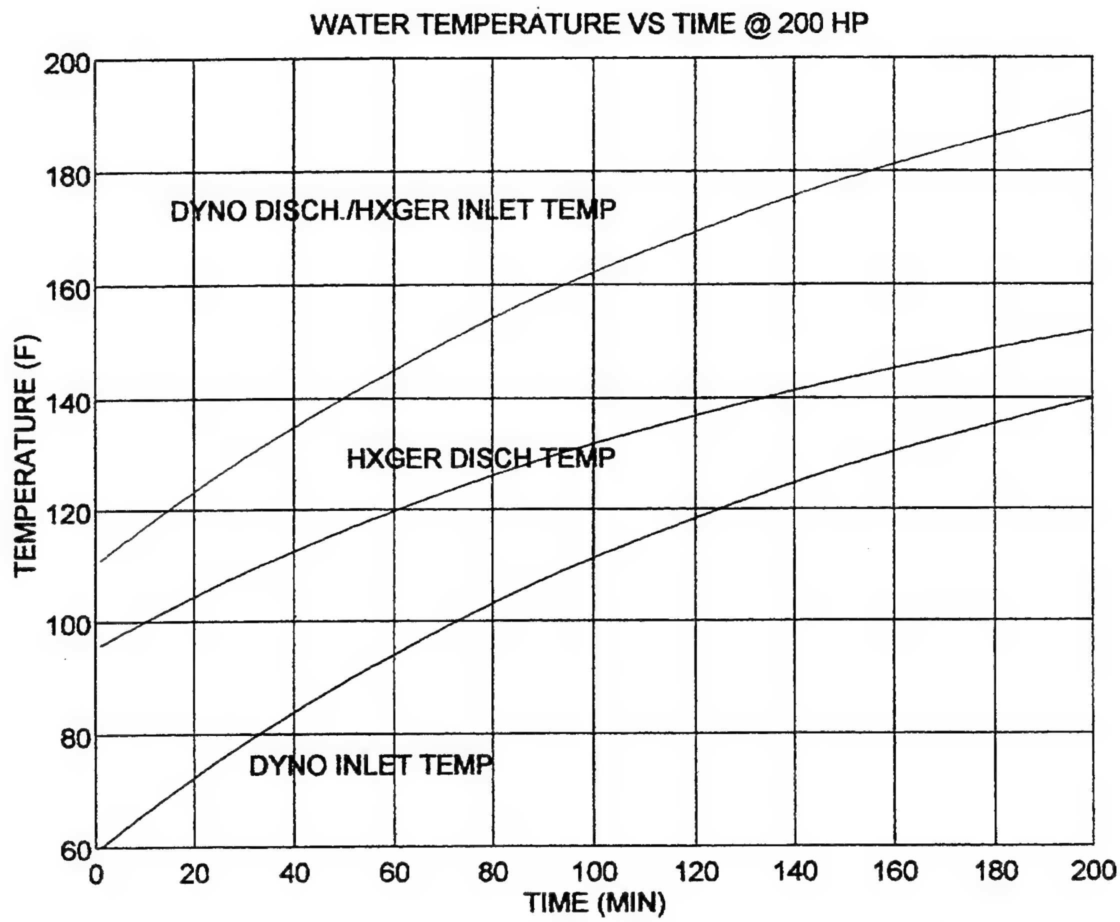


Figure 6.3. Temperature Curves Verses Time for an Engine Load of 200 HP with the Existing, Installed Equipment Configuration.

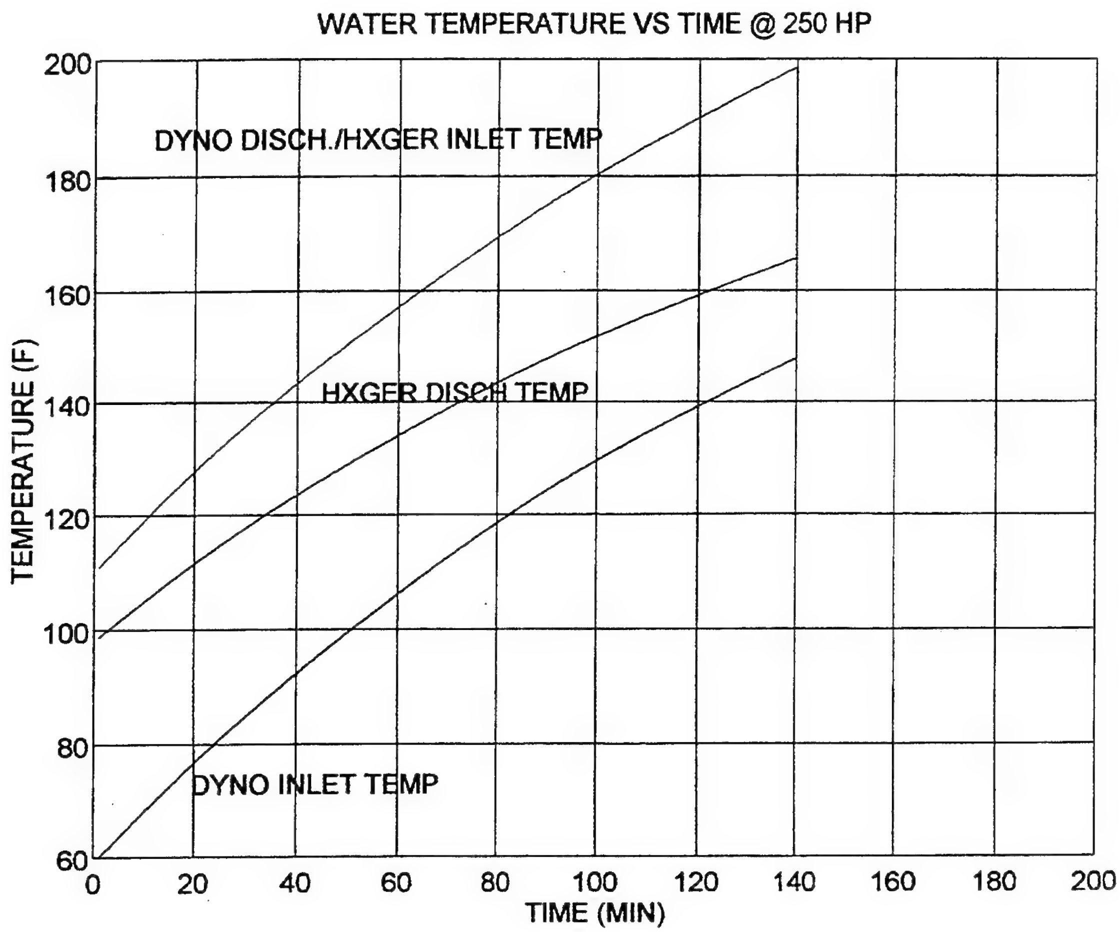


Figure 6.4. Temperature Curves Verses Time for an Engine Load of 250 HP with the Existing, Installed Equipment Configuration.

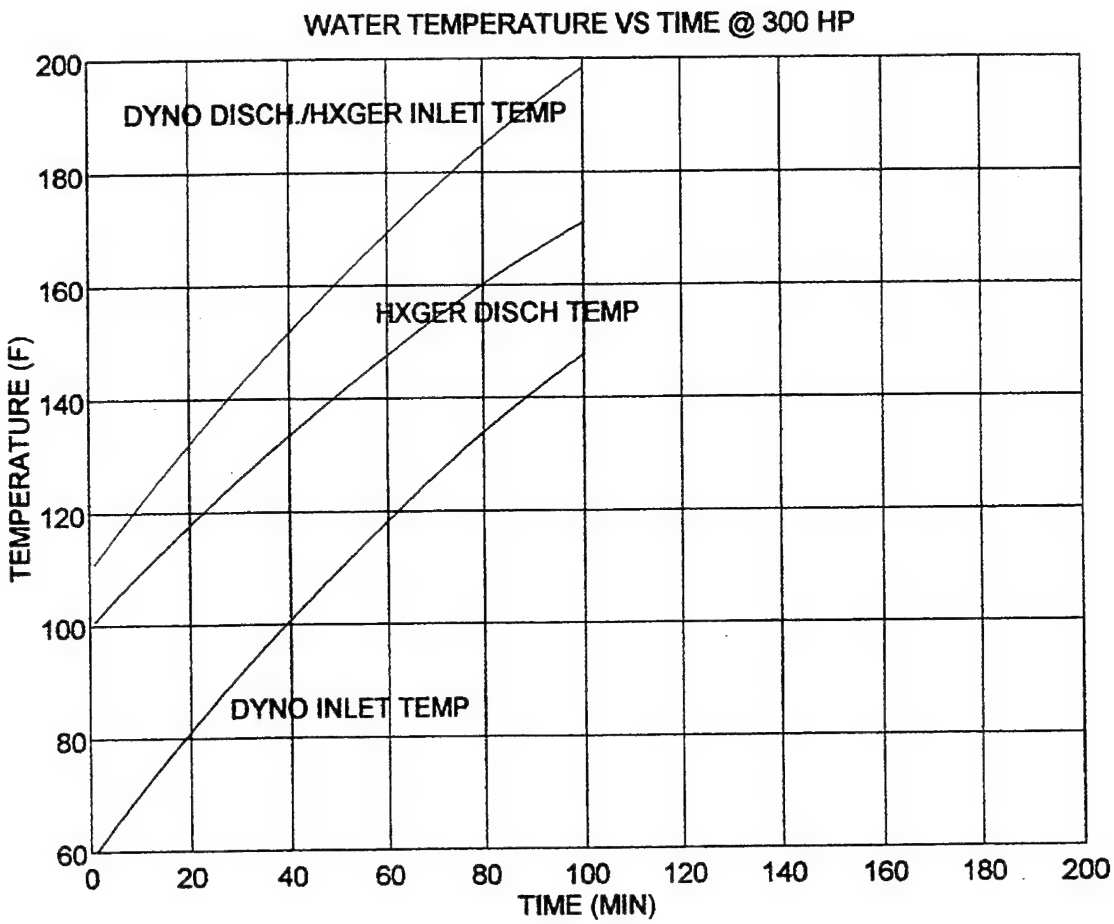


Figure 6.5. Temperature Curves Verses Time for an Engine Load of 300 HP with the Existing, Installed Equipment Configuration.

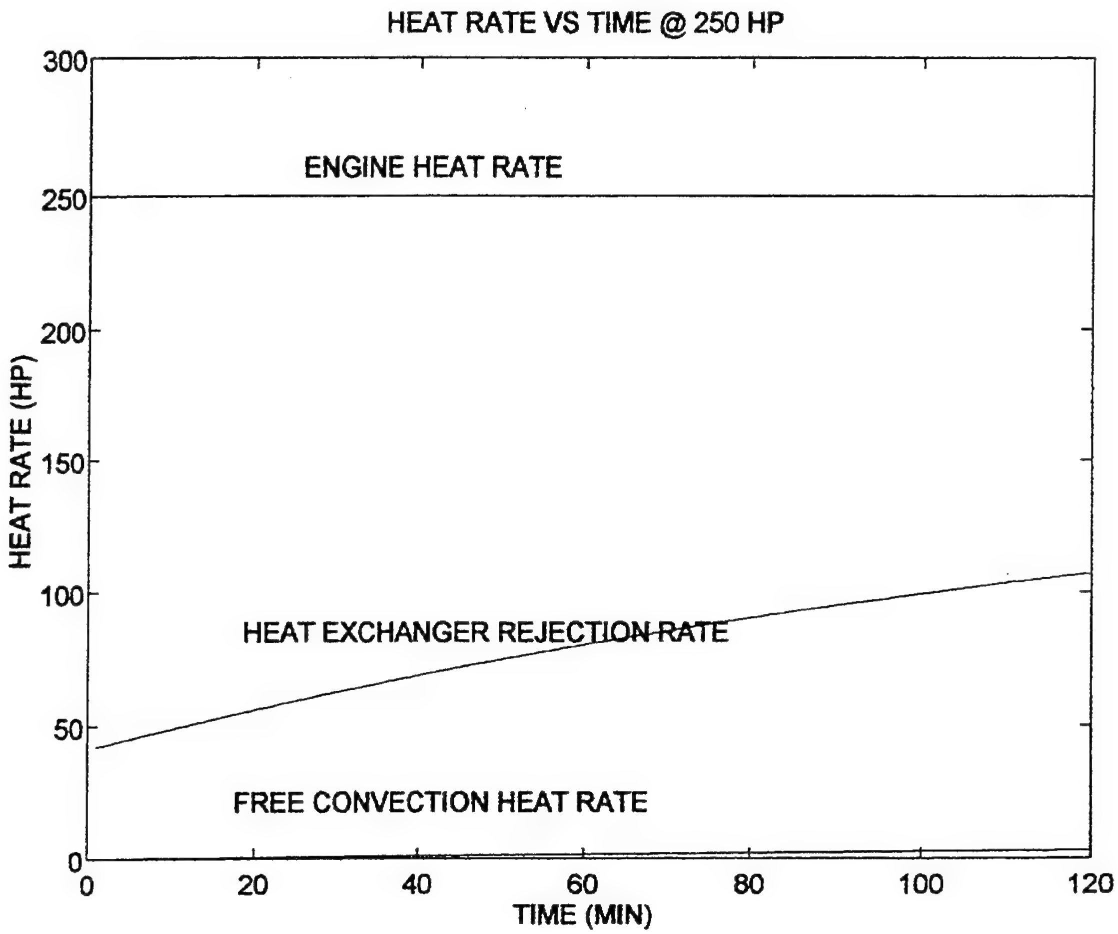


Figure 6.6. Engine Heat Addition Verses Time for an Engine Load of 250 HP with the Existing, Installed Equipment Configuration.

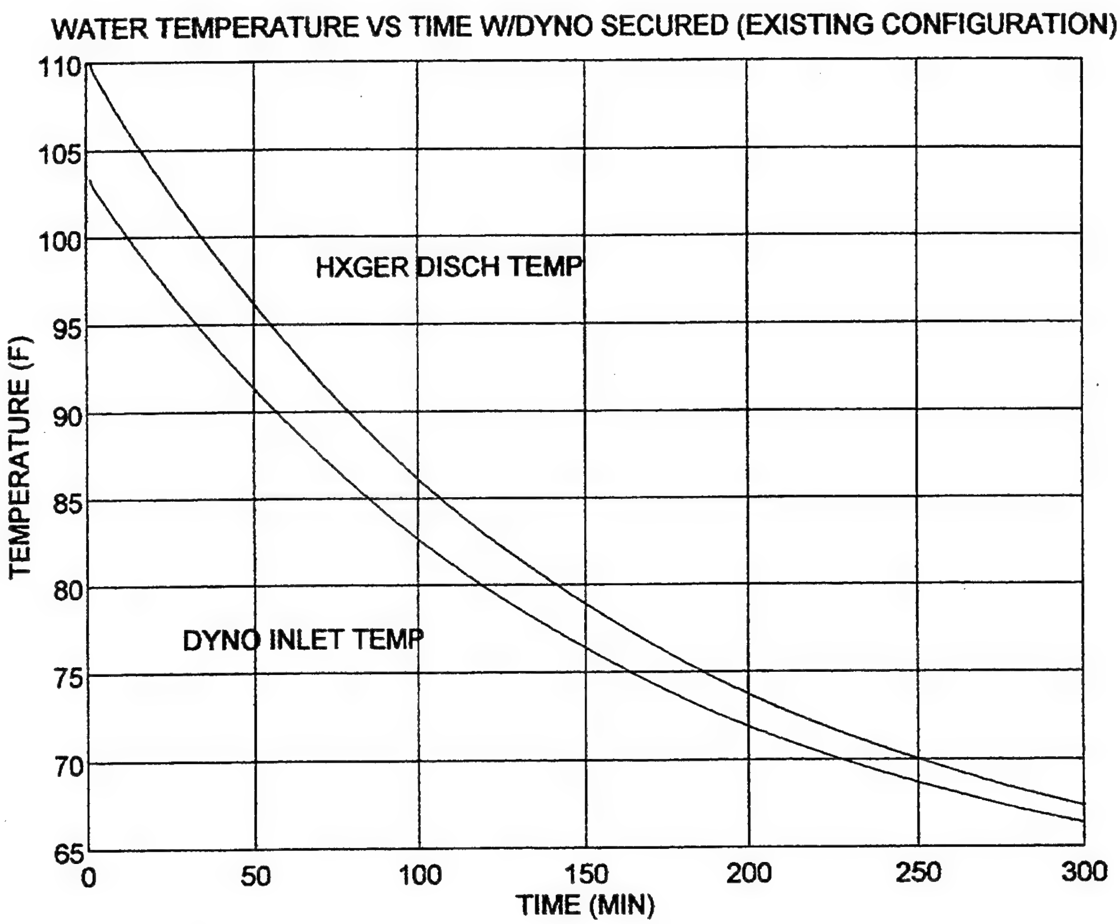


Figure 6.7. Temperature Curves Verses Time with the Dynamometer Secured with the Existing, Installed Equipment Configuration.

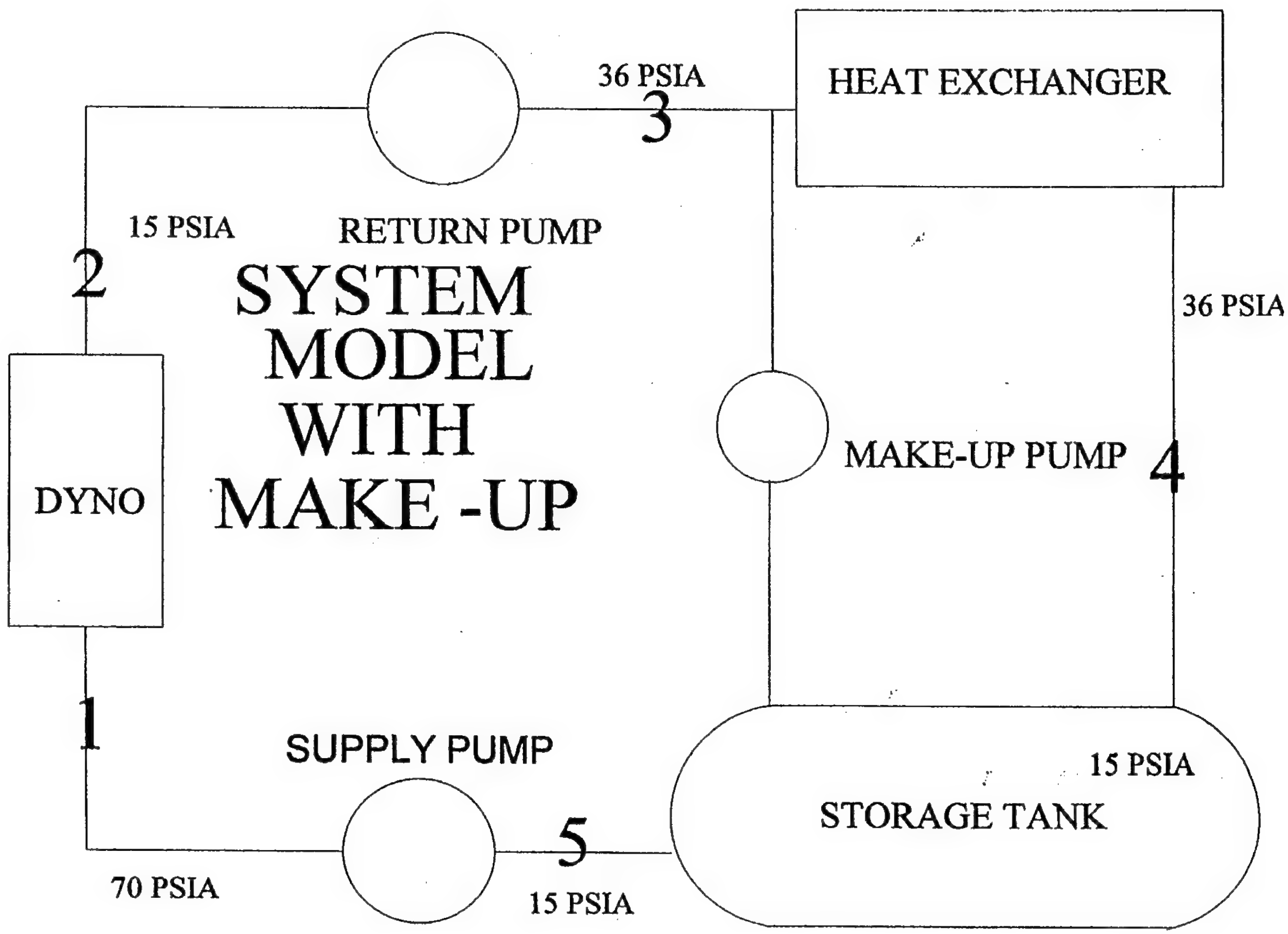


Figure 6.8. Thermodynamic System Model with 5 gallon Make-Up Pump Installed

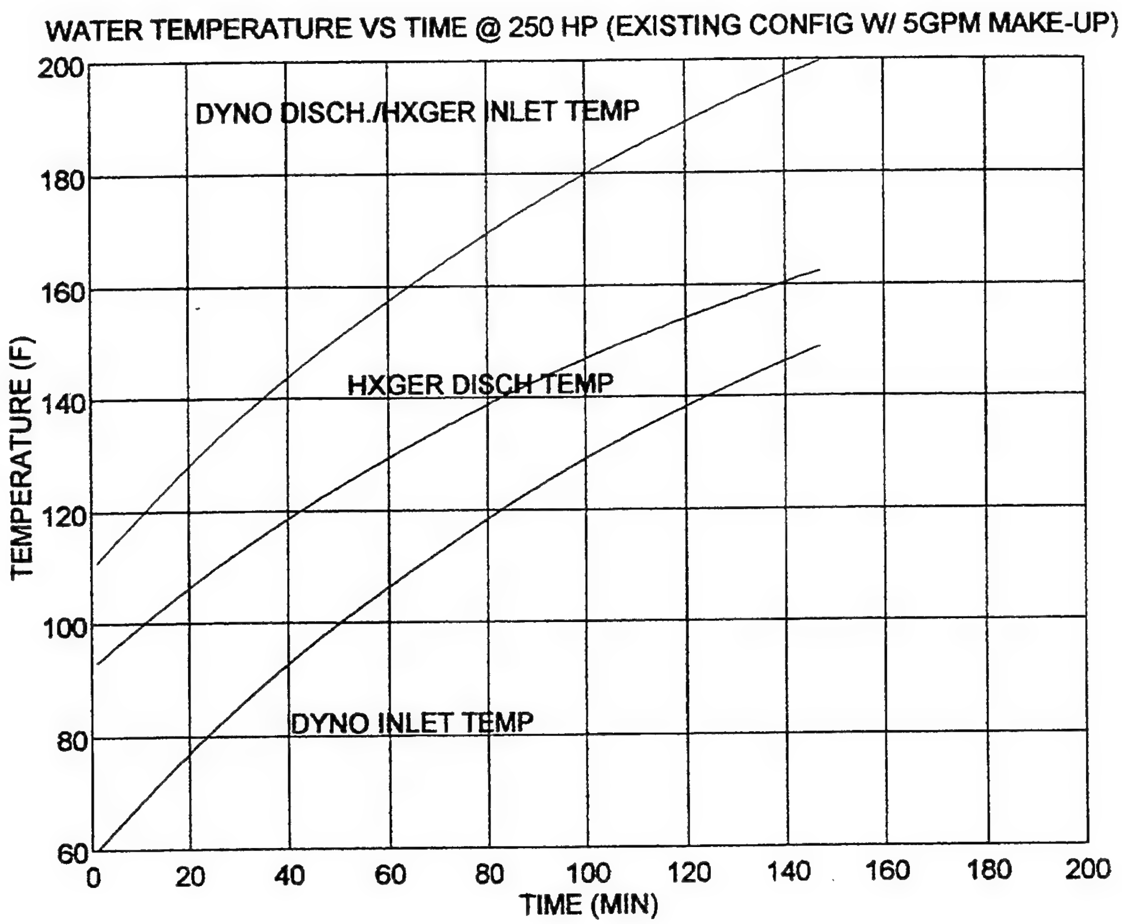


Figure 6.9. Temperature Curves Verses Time for an Engine Load of 250 HP with a 5 GPM Make-up Pump Added to the Existing, Installed Equipment Configuration.

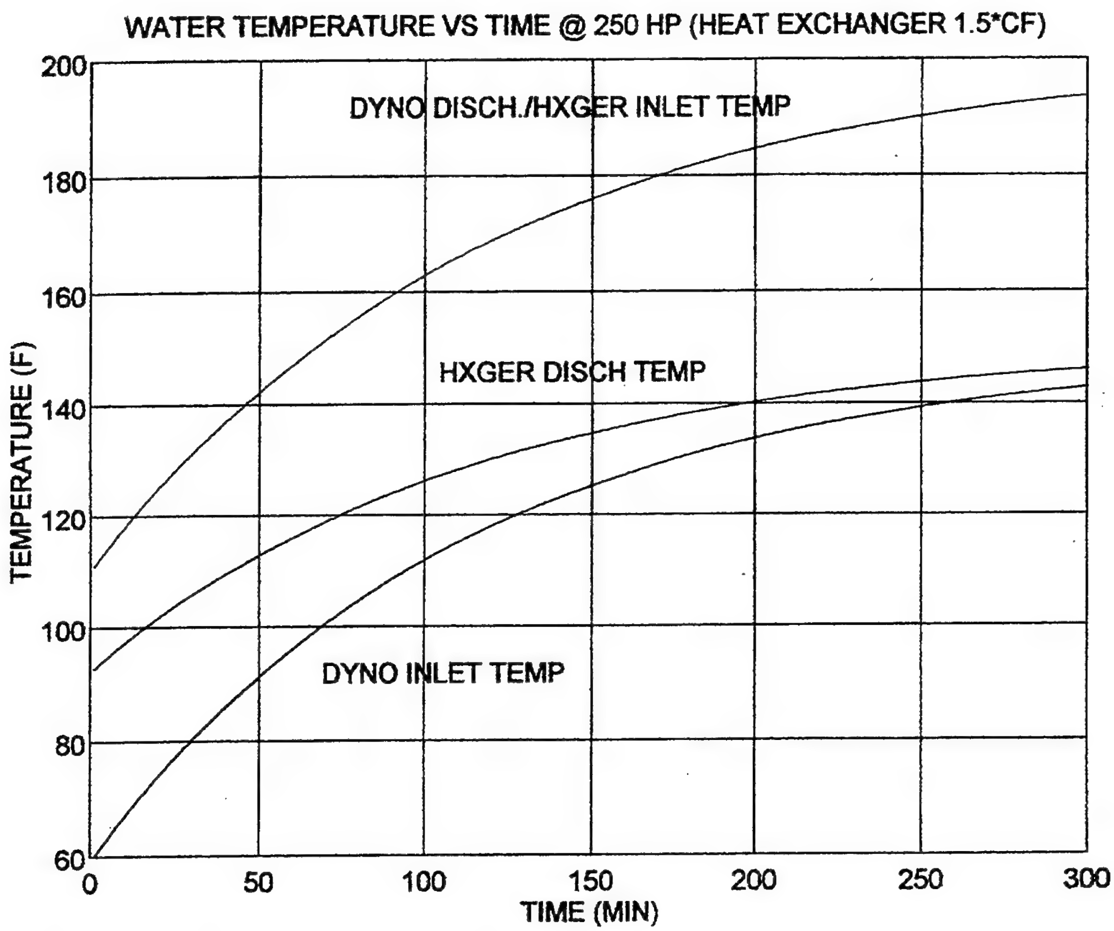


Figure 6.10. Temperature Curves Verses Time for an Engine Load of 250 HP with a Heat Exchanger of Increased Capacity Factor (1.5*CF).

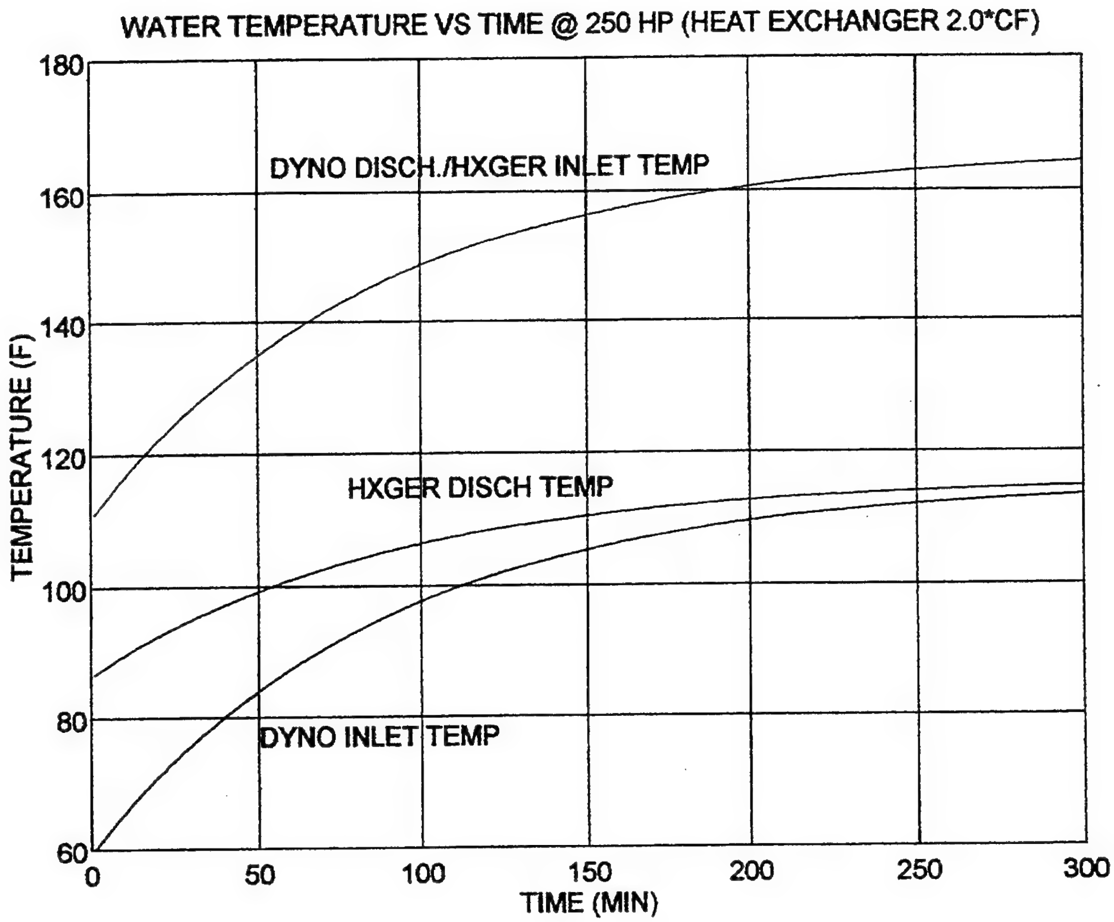


Figure 6.11. Temperature Curves Verses Time for an Engine Load of 250 HP with a Heat Exchanger of Increased Capacity Factor (2.0*CF).

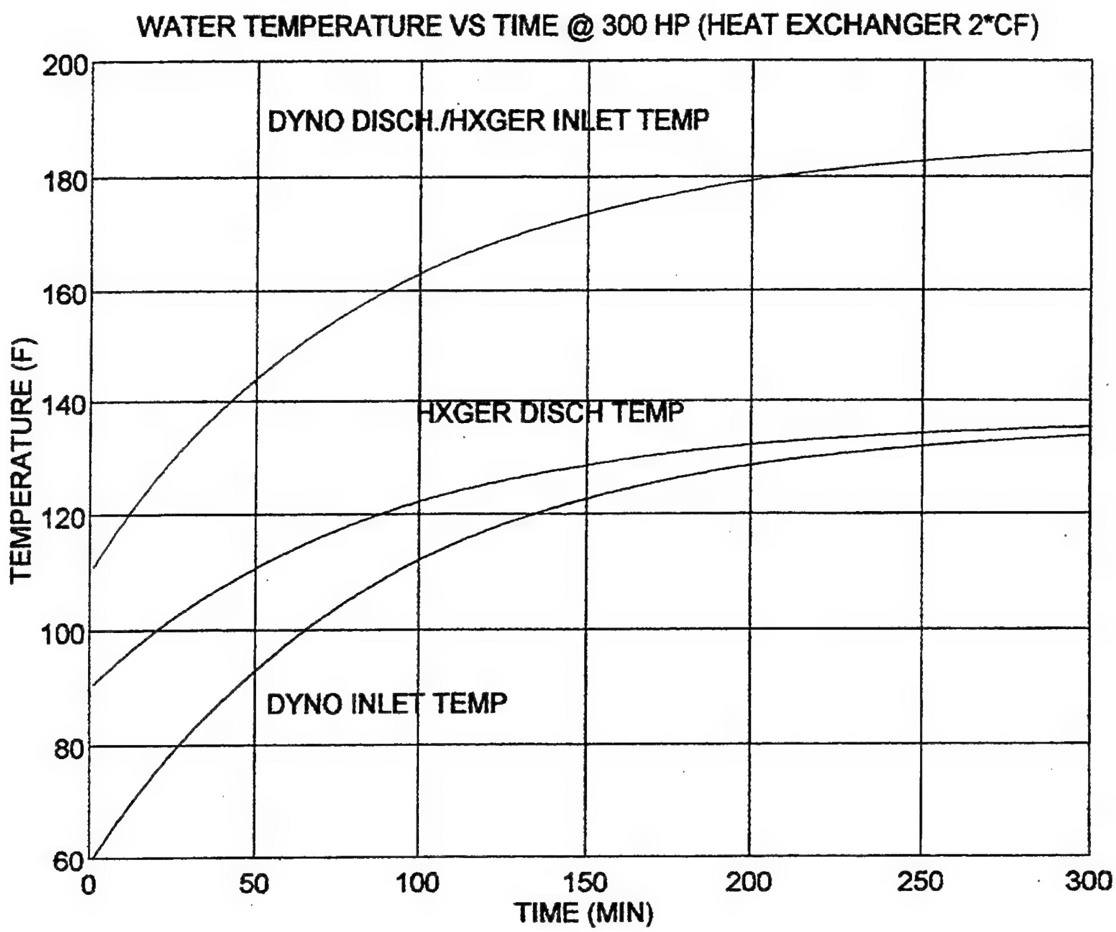


Figure 6.12. Temperature Curves Verses Time for an Engine Load of 300 HP with a Heat Exchanger of Increased Capacity Factor (2.0*CF).

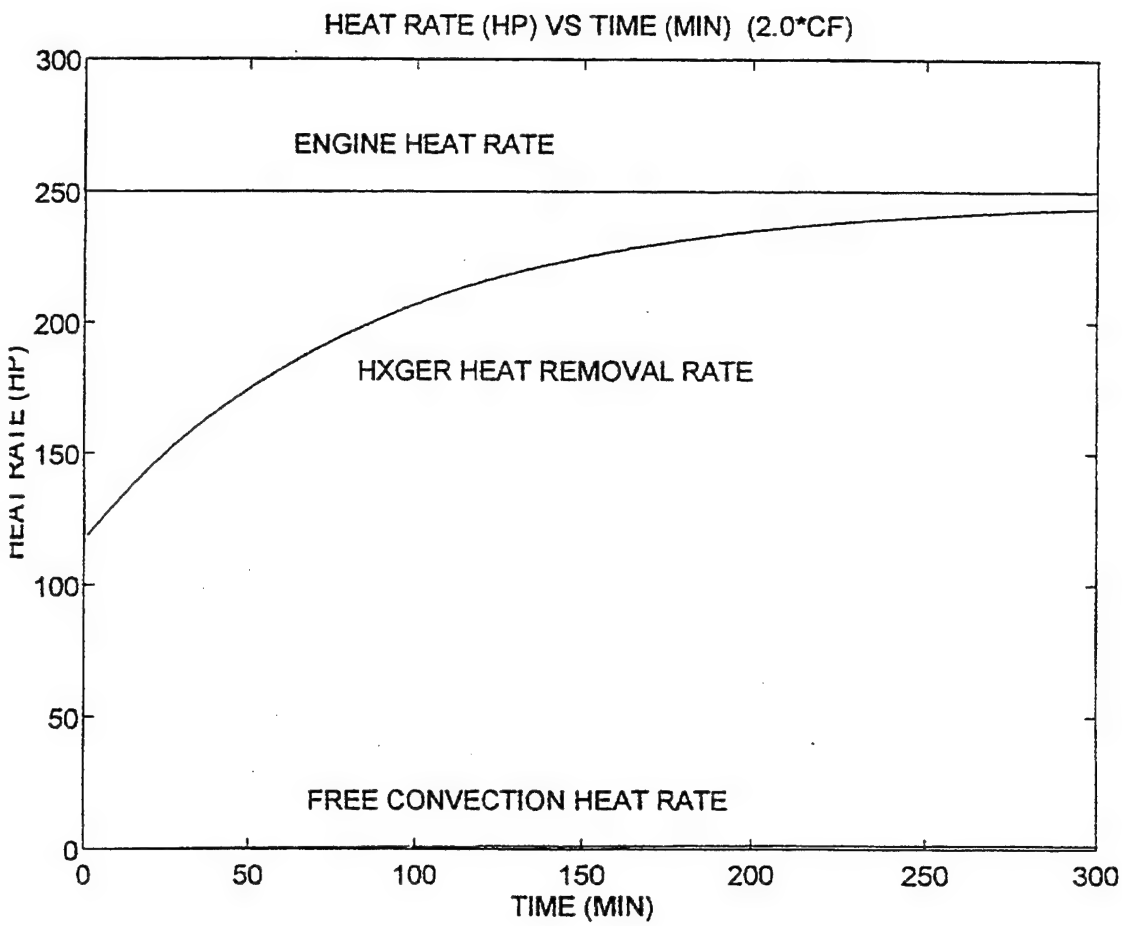


Figure 6.13. Heat Exchanger Extraction Rate Verses Time for an Engine Load of 250 HP with a Heat Exchanger of Increased Capacity Factor (2.0*CF).

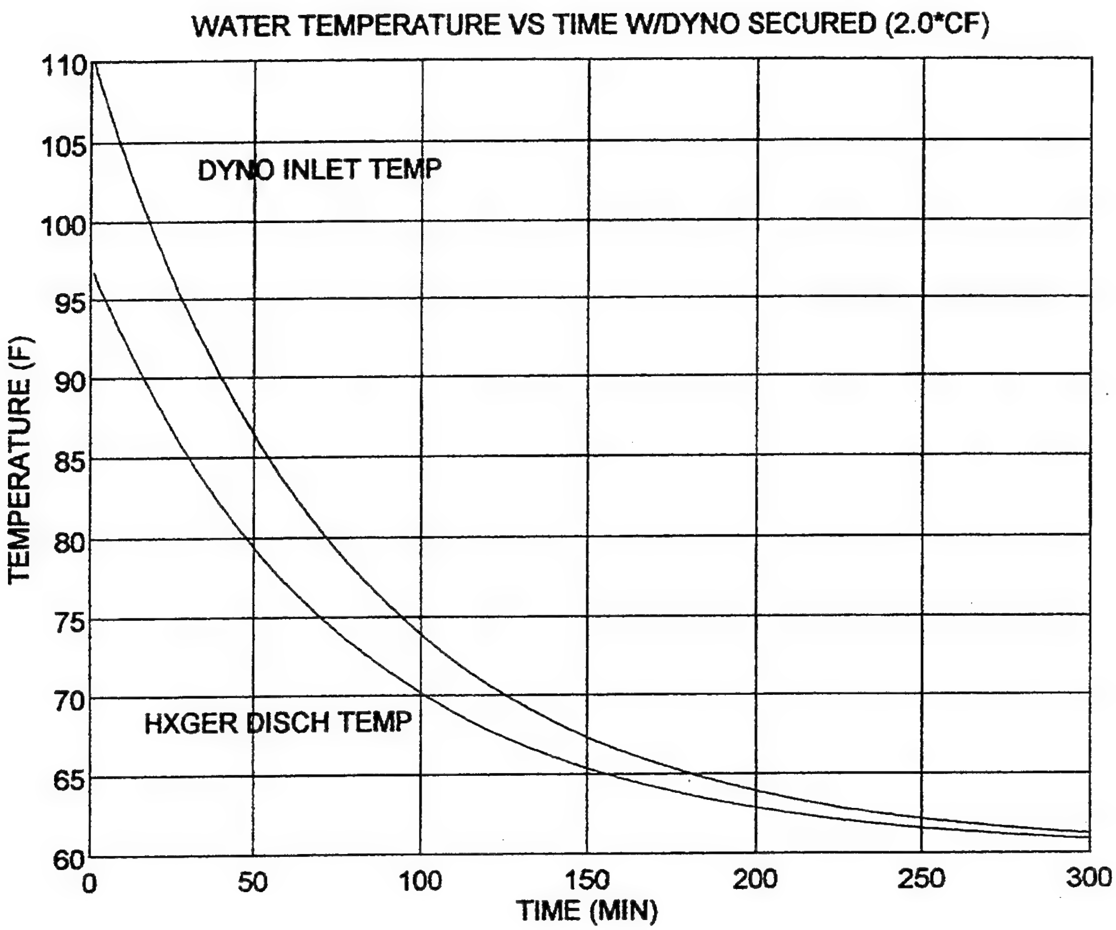


Figure 6.14. Temperature Curves Verses Time with Dynamometer Secured and a Heat Exchanger of Increased Capacity Factor (2.0*CF).

VII. STANDARD AND EMERGENCY OPERATIONAL PROCEDURES

A. INTRODUCTION

The objective of this chapter is to discuss the basic philosophy and decision making process used in developing the Standard Operational Procedures (SOP) for the light off, operation, and shutdown of the gas turbine engine and dynamometer test system. A discussion of Emergency Operational Procedures (EOP) is also presented.

The primary goal in the development of the standard operational procedures was to produce a detailed step by step procedure which can be followed by an operator with a general knowledge of the overall system. A procedure that is both logical and organized by component system and location is also desired. The major criteria are both safety of personnel and to prevent damage to equipment.

In order to accomplish the above goals, the Standard Operational Procedure is subdivided into five procedures:

*Master Light Off Procedure (MLOP)

*Fuel Oil System Recirculation Procedure (FOSRP)

*Cooling Water System Recirculation Procedure (CWSRP)

*Normal Shutdown Procedure (NSP)

*Emergency Shutdown Procedure (ESP)

The above written procedures are contained in Appendix E.

B. MASTER LIGHT OFF PROCEDURE (MLOP)

The Master Light Off Procedure (MLOP) is essentially a safety space walk through, system verification, system alignment, and engine lightoff check list. During the visual inspection of the test cell and auxiliary machinery pad, emphasis is placed on removing flammable hazards and foreign object debris from the test cell, as well as, checking for leaks and damaged equipment. After completion of the safety walk through and system alignment portion, the operator commences with dyno control console settings and engine checks. The remaining portion of the procedure is the actual engine start-up.

C. FUEL OIL SYSTEM RECIRCULATION PROCEDURE (FOSRP)

If the gas turbine test cell had been idle for more than 30 days or the ambient air temperature is less 50 °F, the fuel system must be recirculated in order to ensure no paraffin separation is present. The Fuel Oil System Recirculation Procedure (FOSRP) is written to accomplish this task. The first portion of the procedure involves a visual inspection of the system for leaks and flammable materials. Next, the operator conducts and verifies system alignment. Finally, the fuel oil supply pump is energized and the system is monitored for leaks.

D. COOLING WATER SYSTEM RECIRCULATION PROCEDURE (CWSRP)

If the water cooling system has been idle for more than 30 days, a high degree of oxidized metal particulate will form inside the steel storage tank and system piping. The Cooling Water System Recirculation Procedure (CWSRP) is used to recirculate the water in the system, by using a supply pump, filtration unit, and the dyno bypass valve, to remove the particulate matter.

E. MASTER NORMAL SHUTDOWN PROCEDURE (MNSP)

During a normal shutdown, the operator returns the gas generator speed (N1) back to the idle position and allows the engine to run for two minutes for sufficient engine cool down. After the two minute cool down period, the dynamometer fuel pump is secured effectively cutting off fuel to the engine. After monitoring for a post shutdown fire, the operator secures all the auxiliary support equipment and isolates the fuel, air, and cooling water systems from the test cell.

F. EMERGENCY SHUTDOWN PROCEDURE (ESP)

The emergency shutdown procedure is an accelerated normal shutdown. However, the operator actions of returning N1 speed to idle and allowing for a two minute system cool down are omitted. After completing the immediate action of turning off the dyno fuel pump off and placing the gas generator throttle lever at the 0 RPM position, the operator continues with procedure MNSP after N1 speed is at 0 RPM.

G. SUMMARY

In summary, the master light off and shutdown checklists are modified versions of the dynamometer start up checklist [Ref. 5: p. 21] and the airframe start up procedures used in the OH-58 helicopter. [Ref. 12:p. 8.6-8.8] These procedures were researched, modified, and tailored for use in the gas turbine test cell. The standard operational procedures, as used by operator, are contained in Appendix E.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The component integration of the Allison T63-A-700 gas turbine engine with the Superflow 901-SF dynamometer test system is complete. Although the generic auxiliary support systems provided by the building contractor were not specifically designed for the Allison engine or the Superflow dynamometer, the systems were adequate to support engine testing after various modifications. The water system, fuel system, and oil system are fully installed. The air system is complete with the exception of the exhaust ducting and nozzle assembly from the gas turbine engine exhaust to the building uptakes. All electrical components have been purchased, however, the remote breaker panel and the motor control box for the return pump must still be installed in the auxiliary equipment pad's local operating panel.

The engine has been mounted on the dynamometer and the drive shafting has been installed. The Superflow 901-SF engine stand provided excellent structural support for mounting of the engine, fuel filters, the solenoid shutoff valve, the oil storage tank, and the oil cooler. Therefore, the engine, dynamometer, and most accessories are connected as one integral unit. Since the engine stand is mounted on casters, this attribute allows for full system mobility with minimal system disassembly. The use of the dyno engine stand for accessory mounting, also allowed for a "clean" overall appearance; one that is free from disarray caused by numerous connections and structural mounting supports.

Although the Superflow 901-SF dynamometer test system was designed principally for internal combustion engines, it was found to be suitable for T63-A-700 gas turbine engine operations after some modifications. The major modifications were in the structural support of the engine mounting brackets and the redesigned output shafting as was discussed in Chapter III.

The most difficult aspect in the design of the test facility was predicting overall cost. This was caused primarily by component matching between gas turbine engine parts and airframe parts. The OH-58 helicopter is essentially two separate designs: the Allison gas turbine engine and the Bell Helicopter airframe.

Although the present design for the test facility has many strong points and advantages, there are some areas which need to be improved. Firstly, a common base plate needs to be fabricated and installed on engine test stand under the engine's front and rear supports. When conducting vibration analysis using various isolation mounts, a common base plate would allow for easy placement of shims and precise output shaft alignment. Secondly, there are two items which need to be completed by the Mechanical Engineering building contractor. The air intake fire shutters are not wired with a smoke detector or temperature sensor for automatic operation as specified in the building design drawings. Also, the 450 VAC electrical outlet inside the test cell is powered by 115 VAC and needs to rewired in accordance with the building specifications.

It is also recommended that a full maintenance plan be developed for proper maintenance of the engine and dynamometer, as well as, the auxiliary support equipment. The technical manuals specify various periodic maintenace practices which will prolong their operating life. In the Appendix, various equipment lists are enclosed for ease in identifying replacement parts to accomplish maintenance procedures and equipment repair / replacement.

Finally, even though Standard Operational Procedures (SOP) and Emergency Operational Procedures (EOP) have been written as part of this document, these are only preliminary procedures and should be reviewed and modified by the operators and supervisors periodically for improvements and changes to the procedures.

APPENDIX A. DETAILED DRAWINGS OF GAS TURBINE ENGINE MOUNTING SUPPORTS AND TORQUE PLATE

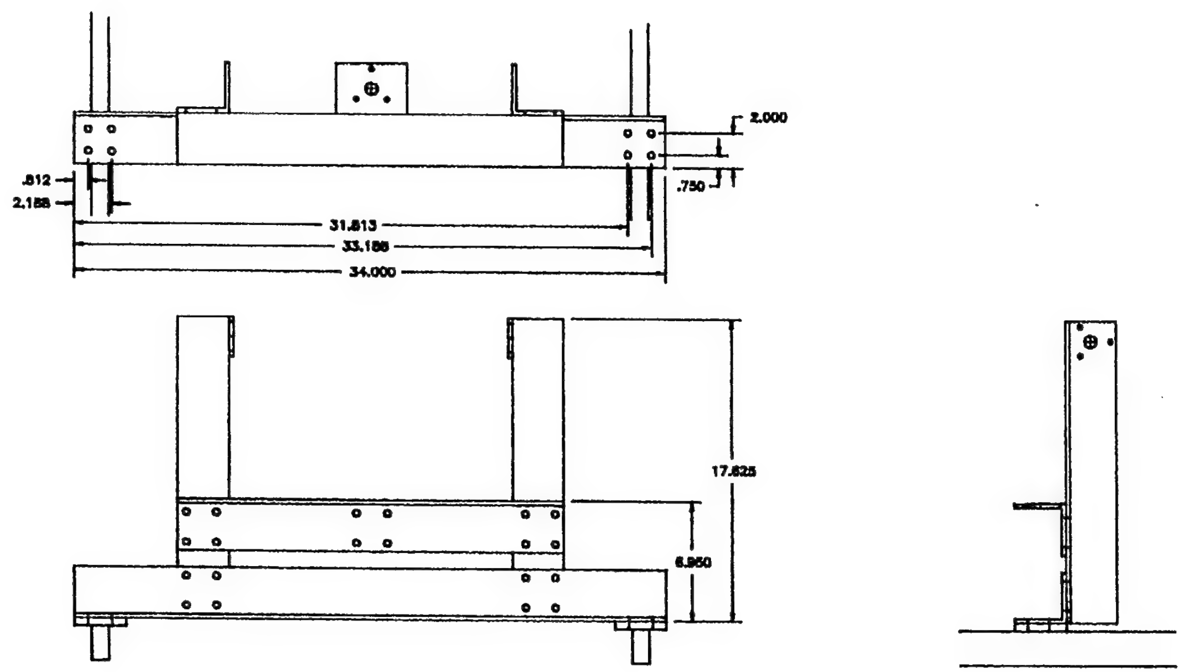


Figure A.1. Detailed Drawing of Engine Front Support.

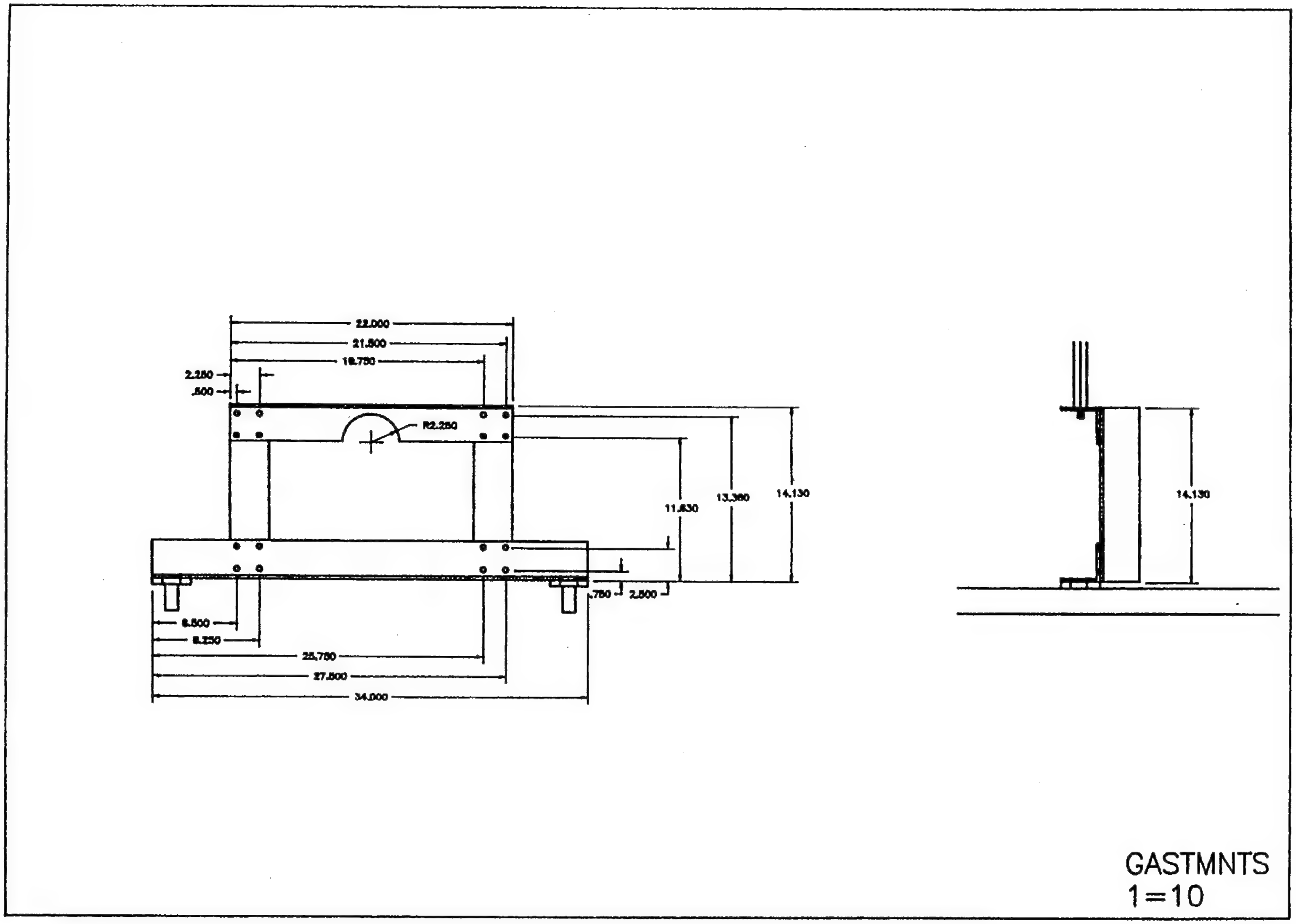


Figure A.2. Detailed Drawing of Engine Rear Support.

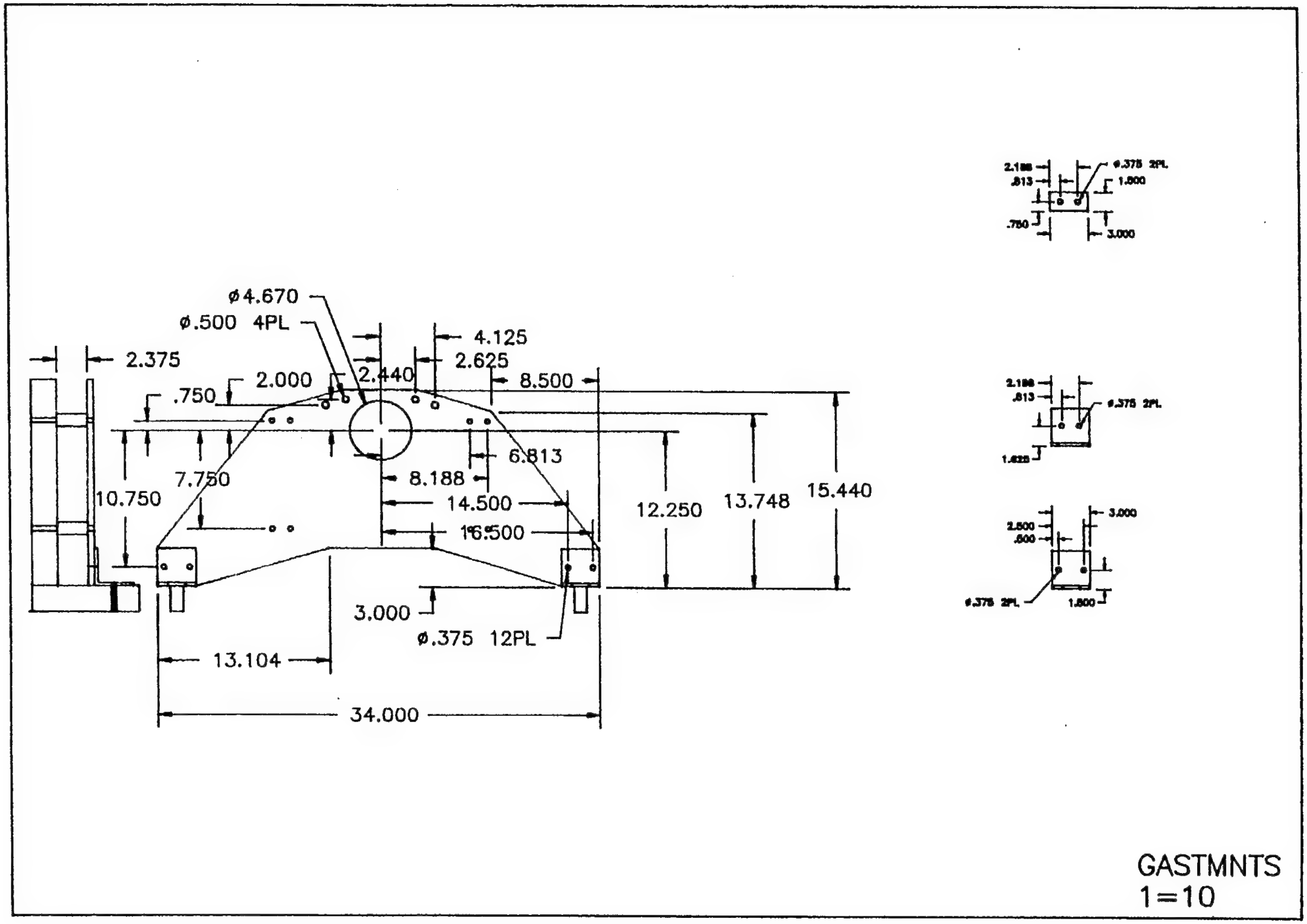


Figure A.3. Detailed Drawing of Dynamometer Torque Plate.

APPENDIX B. EQUIPMENT LISTING FOR THE AUXILIARY MACHINERY PAD

EQUIPMENT	MANUFACTURER	VENDOR	MODEL NUMBER
Heat Exchanger	Young Radiator Co.	C.H. Bull Co.[1]	MWC 26D1Q
Cooling Water Supply Pump	Bell & Gossett	Bell & Gossett[2]	Series 1531 Centrifugal Pump
Fuel Oil Supply Pump	Tuthill Corporation	Tuthill Corporation[3]	Model 1 LEV
Cooling Water Return Pump	Teel	W. W. Grainger[4]	Model 1P955
Fuel Oil Storage Tank	Convault	Convault[5]	Model 500 2HF
Cooling Water Storage Tank	National BD	Roy E. Hanson MFG[6]	Serial # 352602

NOTE:

1. C.H. Bull Co.
   233 Utah Avenue
   South San Francisco, CA 94080
   (415) 871-8448

2. Bell and Gosset
   8200 N. Austin Ave.
   Morton Grove, IL 60053
   (312) 966-3700

3. Tuthill Corporation
   12500 South Pulaski Rd
   Chicago, Il 60658
   (312) 389-2500

4. W.W Grainger
   1334 Dayton Street
   Salinas, CA 93981
   (408) 757-0991

5. Convault
   4109 Zeering road
   Denair, CA 95316
   (800) 222-7099

6. Roy E. Hansen MFG
   Los Angeles, CA

APPENDIX C. AUXILIARY SUPPORT SYSTEMS EQUIPMENT LISTINGS

C.1. COOLING WATER SYSTEM EQUIPMENT LISTING

Part Number	Vendor	Nomenclature
1P955	Grainger[1]	return pump, 2 HP, centrifugal, self priming, internal check valve
5E475	Grainger	globe valve, 2" (bronze)
6P969	Grainger	gate valve, 2" (bronze)
3P574	Grainger	water suction hose (1.5"dia) 25 ft lengths
3P584	Grainger	water discharge hose(3" dia) 25 ft lengthS
4X515	Grainger	pressure gage (0-100 psi)
2A608	Grainger	temperature gage (0-250F)
2W403	Grainger	1 9/16-2.5" hose clamps
5X446	Grainger	2-5/8-4.5" hose clamps
1A527	Grainger	1/4-5/8" hose clamps
1A528	Grainger	5/16-7/8" hose clamps
5X444	Grainger	0.5-1-1/8" hose clamps
5X443	Grainger	3/8-7/8" hose clamps
1A529	Grainger	.5-1.25" hose clamps
3P878	Grainger	1/4" male NPT brass plugs
3P880	Grainger	1/2" male NPT brass plugs

3P879	Grainger	3/8" male NPT brass plugs
3P870	Grainger	3/8"X1/4"NPT female NPT brass bushings
3P872	Grainger	1/4" male NPTX 1/4" compression brassbushings
2P151	Grainger	1/4" 45 deg brass flare nuts
5E225	Grainger	permatex RTV silicone gasket sealer
5E223	Grainger	red RTV silicone gasket sealer
5E212	Grainger	loctite, thread locker 222
5A228	Grainger	loctite thread locker 242
10825K5	FILTREX[2]	50 micron water filter CPL 130-020MT

C.2. FUEL OIL SERVICE SYSTEM

Part Number	Vendor	Nomenclature
PR-7 series	GO INC[3]	pressure reducing regulator (55/12 psi)
SS-RL4M8F8	Sunnyvale Valve[4] (Swagelock)	relief valve 1/2" inlet 1/2" discharge adjustable
SS-CHF12-1	Sunnyvale Valve	check valve 3/4" NPT female 316 stainless steel, 1 psi cracking pressure
B-45F8-42DC	Sunnyvale Valve	solenoid valve, 24 volt, 1/2" NPT
PB-8	Sunnyvale Valve	fuel hose (75 ft
B-PB8-PM8	Sunnyvale Valve	1/2" push on hose barb male NPT
5E455	Grainger	gate valve threaded 1/2
2840009399395	Federal Stock	nozzle assembly, fuel spray

2915010402607	Federal Stock	filter element (fuel)
P1147G	FRAM	filter element
P1146G	FRAM	filter element

C.3. ELECTRICAL SYSTEM EQUIPMENT LISTING

Part Number	**Vendor**	**Nomenclature**
6Z764	Grainger	battery charger 20/2 amp
4P052	Interstate Battery[5]	4 deep cycle marine batteries
E30EA	Bell Electrical[6] 120(Cutler-Hammer)	two button momentary switch with VAC light
E30KE130	Bell Electrical	black start button
E30KE231	Bell Electrical	red stop button
E30KJ11	Bell Electrical	motor run lens
E30DG	Bell Electrical	push-button with off release bar
10250TN15	Bell Electrical	NEMA1 enclosure, 6 hole, grey
DH361OGK	Bell Electrical	switch, NEMA1 enclosure, fusible, heavy duty,3 pole, 480 VAC
MCC 2100	Bell Electrical	motor control cabinet
2925011434229	Federal Stock	starter generator
5945007552301	Federal Stock	starter/generator relay
6110001388687	Federal Stock	voltage regulator
8040-002	Turbomotive[7]	N1 & N2 Tachometers
CDPEDA	Turbomotive	engine dress adapter

C.4. AIR SYSTEM EQUIPMENT LISTING

Part Number	Vendor	Nomenclature
3C243	Grainger	ceiling intake shutters
2C904	Grainger	shutter motors
8.13/16.003N5052	Texas Almet Inc.[8]	aluminum honeycomb sheet
GT12/200	Farr Sales & Svce.[9]	Riga Flo air filter (24X24X12)
TYPE 8	Farr Sales & Svce.	holding frame (24x24)
C-80	Farr Sales & Svce.	fasteners
8045-033	Turbomotive[9]	instrumented compressor bellmouth
9226T5	Carr Supply[10]	20-mesh screen (304 stainless steel)
9226T47	Carr Supply	18-mesh screen (304 stainless steel)
N/A	Valley Fab.[11]	structural steel C-channel C-4X6.25 (20')
N/A	Valley Fab.	perforated alum sheet (.5" dia holes)
N/A	Valley Fab.	perforated alum sheet (1.0" dia holes)
N/A	Valley Fab.	alum sheet (.125X36X144")
N/A	Valley Fab.	steel box beam (2x2")
2840001316405	Federal Stock	duct, exhaust rh
2840002229249	FederalStock	duct, exhaust lh

C.5. OIL SYSTEM AND SPECIAL EQUIPMENT LISTING

Part Number	Vendor	Nomenclature
5T903	Grainger	dry chemical fire extinguishers
9150001806266	Federal Stock	lubricating oil MIL-L-23699
2840001988610	Federal Stock	tank, lubricating oil
2935001216554	Federal Stock	cooler, lubricating
Special Fab.	Turbomotive	shaft
Special Fab.	Turbomotive	adapter (shaft)

NOTE :

1. W.W. Grainger
   1334 Dayton street
   Salinas, CA 93901
   (408) 757-0991

2. FILTREX Corp.
   1945 Alpine Way
   Hayward, CA 94545
   (510) 783-3700

3. GO Inc.
   305 S. Acacia St
   San Dimas, CA 91773
   (909) 599-6245

4. Sunnyvale Valve
   929 Weddell Court
   Sunnyvale, CA 94089
   (408) 734-3145

5. Interstate Battery
213 N. Main
Salinas, CA 93901
(408)758-6411

6. Bell Electrical
536 Brunken Ave.
Salinas, CA 93901
(408) 758-6110

7. Turbomotive Inc.
285 Welton St
Hamden, CT 06517
(203) 789-0243

8. Texas Almet Inc.
2800 E. Randall Mill Rd
Arlington, TX 76011
(817) 649-7056

9. Farr Sales and Service
2201 Park Place
El Segundo, CA 90245
(310) 536-6787

10. Carr Supply Co.
PO Box 54960
Los Angeles, CA 90054
(213) 692-5911

11. Valley Fabricators
637Abbott Street
Salinas, CA 93912
(408) 757-5151

APPENDIX D. MATLAB COMPUTER SIMULATION PROGRAM CODES AND HEAT EXCHANGER SPECIFICATION SHEET

D.1. MATLAB CODE FOR THERMODYNAMIC SIMULATION OF THE COOLING WATER SYSTEM.

```
clear

ttable=60:10:200;

hfor15=[28.10 38.09 48.08 58.06 68.04 78.02 88.00 97.99 107.98 117.98 127.98 138.00
148.02 158.05 168.09];

hfor36=[28.16 38.15 48.13 58.11 68.09 78.07 88.05 98.04 108.03 118.03 128.03 138.05
148.07 158.10 168.14];

hfor70=[28.26 38.25 48.23 58.20 68.18 78.16 88.14 98.13 108.12 118.11 128.12 138.13
148.15 158.18 168.22];


% h1,h2,h3,h4,h5     =    enthalpy values (Btu/lbm)
% p1,p2,p3,p4,p5     =    pressure values (psi)
% t1,t2,t3,t4,t5     =    temperature values (F)
% vgps               =    volumetric flow rate (gps)
% mdot               =    mass flow rate (lbm/sec)
% tamb               =    ambient air temp. (deg F)
% hp                 =    engine power (hp)
% q12                =    heat added by dyno water brake (Btu/sec)
% cf                 =    heat exchanger capacity factor (Btu/sec F)
% q34                =    heat extracted by heat exchanger (Btu/sec)
% delt               =    time interval (sec)
% htank              =    mixing cup enthalpy for water supply tank (Btu/lbm)
% frc                =    mass fraction of tank volume entering
% vtank              =    volume of tank (gallons)
% delv               =    change in tank volume per unit time
% hpre4              =    enthalpy from previous calculation (Btu/lbm)
% ttank              =    bulk temp. of tank (F)
% g                  =    gravitational accel. (ft/sec^2)
% beta               =    coefficient of thermal expansion (1/R)
% d                  =    diameter tank (ft)
```

```
% nu        =   kinematic viscosity (ft^2/sec)
% RaD       =   Rayleigh number
% Pr        =   Prandtl number
% NuD       =   Nusselt number
% h         =   free convection ht.coef. (Btu/sec ft^2 F)
% q45       =   heat removed from tank by free convection (Btu/sec)
% kair      =   thermal conductivity for air (Btu/sec ft F)
% sarea     =   external surface area of the tank (ft^2)


% define constant variables
        p1      =   70;
        p2      =   15;
        p3      =   36;
        p4      =   36;
        p5      =   15;
        cf      =   0.825;
        vtank   =   1040
        g       =   32.17;
        d       =   4;
        nu      =   1.6e-4;
        Pr      =   .7;
        kair    =   4.54e-6;
        sarea   =   pi*d*12;

% define variables which may change due to operational needs and ambient conditions.

        tamb    =   60;
        time    =   200;
        delt    =   60;
        hp      =   250;
        hpre4   =   Interp1(ttable,hfor15,tamb);
        vgps    =   hp/10/60;
        mdot    =   62.38/7.481*vgps;
        h1      =   zeros(1,time);
        h2      =   zeros(1,time);
        h3      =   zeros(1,time);
        h4      =   zeros(1,time);
        h5      =   zeros(1,time);
        htank   =   zeros(1,time);
        t1      =   zeros(1,time);
        t2      =   zeros(1,time);
```

```
        t3      =       zeros(1,time);
        t4      =       zeros(1,time);
        t5      =       zeros(1,time);
        ttank   =       zeros(1,time);
q23     =       zeros(1,time);
q34     =       zeros(1,time);
q45     =       zeros(1,time);
RaD     =       zeros(1,time);
h       =       zeros(1,time);

t5(1)=60;

for j=1:time

% enthalpy calculation inlet supply pump

h5(j)=interp1(ttable,hfor15,t5(j));

% supply pump inlet and discharge temp.

t1(j)=t5(j);

% supply pump discharge enthalpy calc.

h1(j)=interp1(ttable,hfor36,t1(j));

% heat added from water brake

q12(j)=hp*2545/3600;

% enthalpy at discharge of dyno

h2(j)=(q12(j)+mdot*h1(j))/mdot;

% find temp. at water brake discharge

t2(j)=interp1(hfor15,ttable,h2(j));

% return pump inlet and discharge temp. & enthalpy

t3(j)=t2(j);
h3(j)=h2(j);
```

```
% heat extracted in the ht. ex.

q34(j)= cf*(t3(j)-tamb);

% find enthalpy at discharge of ht. ex.

h4(j)=(mdot*h3(j)-q34(j))/mdot;

% find temp. at discharge of ht. ex.

t4(j)=interp1(hfor36,ttable,h4(j));

% find bulk enthalpy of tank

frc=vgps*delt/vtank;

htank(j)=frc*h4(j)+(1-frc)*hpre4;

hpre4=htank(j);

% find bulk temp. of tank

ttank(j)=interp1(hfor15,ttable,htank(j));

% Rayleigh number for tank (free convection)

beta=1/(460+(tamb+ttank(j))/2);
RaD(j)=g*beta*(ttank(j)-tamb)*d^3*Pr/nu^2;

% ht. coefficient for tank

h(j)=kair/d*(0.6+0.387*RaD(j)^(1/6)/(1+(0.559/Pr)^(9/16))^(8/27))^2;

q45(j)=h(j)*sarea*(ttank(j)-tamb);

% bulk enthalpy of tank

h5(j)=(mdot*htank(j)-q45(j))/mdot;

% bulk temp. of tank

t5(j+1)=interp1(hfor15,ttable,h5(j));
```

```
end

time1=1:time;

t5=t5(:,[2:time+1]);

grid;

plot(time1,t1,'r',time1,t2,'g',time1,t4,'m');grid

xlabel('TIME (MIN)');ylabel('TEMPERATURE (F)');

axis ([0 200 60 200]);

title('WATER TEMPERATURE VS TIME @ 250 HP (STORAGE TANK CAP.
2080GAL) ')

gtext('DYNO INLET TEMP')

gtext('DYNO DISCH./HXGER INLET TEMP')
gtext('HXGER DISCH TEMP')
%print -depsc2 fig6_3
%plot(time1,hp1,'r',time1,q34,'g',time1,q45,'m')
%title('HEAT RATE VS TIME @ 250 HP ( 2.0*CF )');
%axis ([0 300 0 300])
%xlabel('TIME (MIN)');ylabel('HEAT RATE (HP)');
%gtext('FREE CONVECTION HEAT RATE')
%gtext('HEAT EXCHANGER REJECTION RATE')
%gtext('ENGINE HEAT RATE')
```

STANDARD MWC-Q MODEL		CAPACITY FACTOR		WATER FLOW, gpm l/s						FAN							SOUND LEVEL	WATER VOLUME		SHIPPING WEIGHT, lb N			
REMOTE	EXTERNAL	Btu/min-F	J/s-C	DERATE 10%		MIN		MAX		AIR FLOW		POWER		TIP SPEED		ROTATION	dB(A) @ 25 ft 8m			REMOTE		EXTERNAL	
										cfm	m³/s	hp	kw	ft/min	m/s	rpm		gal	l				
* 26D1Q	26E1Q	55	1740	22 (11)	1.4 0.7	63 (30)	3.9 1.9	230 (110)	14.5 6.9	4200	2.0	1.5	1.2	10990	55.8	1750	73	8	30	350	1600	300	1300
46D1Q	46E1Q	60	1900	28 (14)	1.8 0.9	80 (40)	5.1 2.5	290 (150)	18.3 9.5	4500	2.1	1	0.8	8200	41.6	1160	69	11	41	450	2000	380	1700
* 66D2Q	66E2Q	105	3320	36 (18)	2.3 1.1	100 (50)	6.3 3.2	360 (180)	22.7 11.4	8000	3.8	2	1.5	9720	49.4	1160	73	14	53	600	2700	500	2200
86D3Q 86D5Q	86E3Q 86E5Q	190 215	6000 6800	42	2.7	115	7.3	420	26.5	15000 17600	7.1 8.3	3 5	2.2 3.7	10930	55.5	1160	76 78	20	76	950	4200	800	3600
106D5Q	106E5Q	235	7400	47	3.0	130	8.2	480	30.3	19000	9.0	5	3.7	9620	48.9	875	75	23	87	1150	5100	1000	4500
126D5Q 126D7Q	126E5Q 126E7Q	295 315	9400 9900	50	3.1	140	8.8	500	31.5	24000 25600	11.3 12.1	5 7.5	3.7 5.6	10990	55.8	875	77 79	26	98	1350	6000	1150	5100
156V7Q 156V10Q 156V15Q	156E7Q 156E10Q 156E15Q	390 420 475	12300 13300 15000	60	3.8	160	10.0	550	34.8	31500 35000 40000	14.9 16.5 18.9	7.5 10 15	5.6 7.5 11.2	11000	55.9	778	78 80 81	32	120	2300	10200	1750	7800
206V10Q 206V15Q 206V20Q	206E10Q 206E15Q 206E20Q	485 525 580	15400 16600 18400	63	4.0	170	10.8	630	40.0	40000 44000 49000	18.9 20.8 23.1	10 15 20	7.5 11.2 15	11000	55.9	700	79 81 82	40	150	2600	11600	2000	8900
256V15Q 256V20Q	256E15Q 256E20Q	635 705	20000 22300	70	4.4	200	12.6	690	43.5	53000 59000	25.0 27.9	15 20	11.2 15	11000	55.9	618	80 81	48	180	2900	12900	2200	9800
356V15Q 356V20Q 356V25Q	356E15Q 356E20Q 356E25Q	800 875 920	25300 27700 29000	80	5.1	230	14.5	810	51.2	65000 72000 77000	30.7 34.0 36.3	15 20 25	11.2 15 19	11000	55.9	519	78 80 81	65	250	4000	17800	3100	13800
456V15Q 456V20Q 456V25Q	456E15Q 456E20Q 456E25Q	970 1050 1100	30675 33200 34780	87	5.5	250	15.8	950	59.9	75200 82900 87900	35.5 39 41.5	15 20 25	11.2 15 19	10275	52.2	422	81 82 83	83	314	5600	24920	4200	18690

QUIET

QUIET

Figure D.2. Manufacturer Specification Sheet for 26D1Q and 66D2Q Model Heat Exchangers "From Ref.[11]."

APPENDIX E. STANDARD OPERATIONAL PROCEEDURES FOR ALIGNMENT AND OPERATION OF THE GAS TURBINE AND DYNAMOMETER TEST SYSTEM

MASTER LIGHTOFF PROCEDURE (MLOP)

SYSTEM VERIFICATION, ALIGNMENT PROCEDURES, AND OPERATING PROCEDURES

PROCEDURE

PLACING THE GAS TURBINE TEST CELL INTO OPERATION

1. Conduct visual inspection of gas turbine test cell and verify the following:

   a. Ensure all drip pans, piping trenches, and the deck are free of oil, fuel, or any flammable liquids.

   b. Ensure all flammable liquids are stored properly in the flammable liquids locker.

   c. Ensure all small parts, equipment, tools, or objects, which may become airborne debris, are properly stored.

   d. Verify that the gas turbine test cell and work area fire extinguishers are fully charged.

   e. Inspect all piping runs and accessories for loose connections, damage, or leaks.

   f. Ensure all valve handwheels are installed and valve labels are in place.

   g. Inspect the air intake louvers for blockage. Also verify the fire dampers behind the FOD screen are open.

   h. Check the engine battery voltage. Place the batteries on charge if voltage is below 22 VOLTS.

   i. Check fuel level in fuel oil storage tank. Ensure enough fuel is present to support gas turbine operations.

   j. Verify that the water storage tank is full.

2. If gas turbine test cell and diesel test cell have been idle for more than 30 days, the water system and fuel system must be recirculated prior to placing the systems into operation. Proceed to the fuel oil service recirculation procedure (FOSRP) and the cooling water system recirculation procedure (CWSRP).

3. If the ambient air temperature is less 50 °F, the fuel system must be recirculated in order to ensure no paraffin separation is present. Proceed to the fuel oil service recirculation procedure (FOSRP).

4. Ensure the cooling water system filter is clean and free of excessive particulate.

WATER SYSTEM ALIGNMENT

1. Ensure the following valves are in the fully open position:

a. Water storage tank suction valve	CW-1
b. Water supply pump suction valve	CW-2GT
c. Water supply pump discharge valve	CW-4GT
d. Dynamometer sump tank supply valve	CW-6GT
e. Return pump discharge valve	CW-9GT
f. Heat exchanger inlet valve	CW-10
g. Heat exchanger discharge valve	CW-12

2. Ensure the following valves are in the fully closed position:

a. Diesel supply pump suction valve	CW-2D
b. Gas turbine to diesel cross connect valve	CW-5
c. Dynamometer bypass valve	CW-7GT
d. Diesel return pump discharge valve	CW-9D
e. Heat exchanger bypass valve	CW-11

3. Place the local heat exchanger breaker [ ] in the AUTO position.

4. Place the local cooling water supply pump breaker [ ] in the AUTO position.

5. Place the local cooling water return pump breaker [ ] in the AUTO position.

FUEL OIL SYSTEM ALIGNMENT

1. Ensure the following valves are in the fully open position:

a. Fuel oil supply pump suction valve	FOS-2GT
b. Fuel oil supply pump discharge valve	FOS-5GT
c. Fuel oil supply cell isolation valve	FOS-6GT
d. Fuel oil return valve	FOS-12GT

2. Place the local fuel oil supply pump breaker [ ] in the AUTO position.

3. Ensure the fuel oil service flow regulator is adjusted between 6-10 PSIG.

4. Ensure the following valves are in the fully closed position:

a. Diesel fuel oil supply pump suction valve	FOS-2D
b. Fuel oil supply cross-connect valve	FOS-3
c. Fuel oil recirculation valve	FOS-9GT
d. Diesel fuel oil return valve	FOS-10D

5. Ensure the dynamometer to engine fuel line quick disconnect is properly connected.

OIL SYSTEM VERIFICATION

***WARNING**: Synthetic lube oil MIL-L 23699 can cause dermatitis or paralysis. If lube oil contacts skin, immediately flush with water. If clothing becomes saturated remove promptly.*

1. Verify the lubrication oil level in the oil storage tank is above the fill mark (6 gallon level).

2. Ensure the oil pressure sensing line is connected to the dynamometer instrumentation rack connection.

3. Ensure the oil supply and discharge lines are properly connected to accessories gearbox.

4. Ensure the shaft is free to turn by rotating manually.

5. Turn on the lubrication oil cooler cooling fan.

ENGINE CHECKS AND ADJUSTMENTS

1. Check gas generator (N1) fuel control lever travel. Ensure full travel form 0-90° settings. For full travel, lever must contact lever stop. Also ensure that the 0° position actuates the spring fuel cut-off on the governor actuator.

2. Check the power turbine governor (N2) for full travel from control console throttle lever.

3. Ensure all protective covers and plugs are removed from all vents and drains.

4. Ensure the battery charger is disconnected from the storage batteries.

5. Ensure the air flow turbines are connected to the dynamometer instrumentation rack.

6. Obtain the latest barometric reading.

7. Verify that the IGNITION switch and FUEL PUMP switch are in the OFF position.

8. Place the LOAD CONTROL switch in the MANUAL position.

9. Place the THROTTLE CONTROL switch in the MANUAL position.

10. Press the POWER ON push-button to energize the dyno control console.

11. Set the shaft OVERSPEED knob at 6,300 RPM.

12. Set the TEMPERATURE METER knob to the LOAD position. Adjust the manual LOAD CONTROL knob to read 8 VOLTS on the TEMPERATURE/VOLT meter scale.

13. Set the TORQUE/POWER display knob to the LOW scale.

14. Set the SPEED display knob to the LOW speed scale.

15. Adjust the UPPER TEST SPEED knob to 6,000 RPM.

16. Set the fuel specific gravity knob to the proper setting.

17. Turn the FUEL mode knob to the A configuration.

18. Set the AIR-FUEL meter knob in the AIR/2 configuration.

19. Set the water vapor pressure knob to the correct setting.

20. Turn the shutter motor breaker [ ] to the ON position. Ensure that the intake shutters move to the open position.

21. Ensure both test cell entrance doors are closed and latched.

ENGINE STARTING PROCEDURE

1. Before the first engine start, motor the engine and check for oil pressure and leaks. Energize starter to 10,000 RPM and release.

2. Turn the remote cooling water supply pump breaker [ ] to the ON position.

3. Turn the remote heat exchanger breaker [ ] to the ON position.

4. Turn the remote fuel oil pump breaker [ ] to the ON position.

5. Place the N1 gas generator lever in the 0° (fuel cut-off) position using the manual throttle lever on the control console.

6. Place the power turbine governor N2 lever to 90°.

7. Turn the FUEL PUMP switch to the ON position.

8. Turn the remote cooling water return pump breaker [ ] to the ON position.

9. Turn the IGNITION switch ON and press the STARTER push-button simultaneously.

CAUTION

Do not operate ignition for more than three minutes continually in any 30 minute period. The ignition may be operated two minutes on, three minutes off, and two minutes on in any 30 minute period.

10. Verify positive lubrication oil pressure.

11. Monitor all console warning lights.

12. Advance the gas generator throttle lever (N1) to the 30° (idle position) as N1 passes 8,000 RPM (16%).

13. Verify an increase in power turbine speed (N2) by the time N1 speed reaches 20,000 RPM (40%).

14. Monitor turbine outlet temperature. Ensure that TOT does not exceed 1,380 °F for more than ten seconds or 1,700° F for more than one second.

15. Ensure gas generator speed reaches a steady state idle speed of 30,000 RPM (60%).

16. Release the STARTER push-button and turn the IGNITION switch OFF when N1 is at idle (60%).

17. Adjust the manual LOAD CONTROL knob and gas generator control lever as required for engine testing.

***NOTE*:** Abort start by returning the gas generator throttle lever to the 0° position and securing dynamometer fuel pump if any of the following abnormal conditions occur during system start up:

1. Time from starter ON to idle speed exceeds one minute.

2. Engine oil pressure does not start to increase before N1 speed reaches 10,000 RPM (20%).

3. No indication of power turbine speed N2 before gas generator speed N1 reaches 20,000 RPM (40%).

4. Turbine outlet temperature exceeds 1,380 °F for more than 10 seconds or 1,700 °F for more than one second.

5. A WATER SUPPLY warning light illuminates which indicates a supply water pressure of less than 15 PSIG is available to the power absorber.

6. A DYNO PRIME warning light illuminates indicating that the power absorber must be reprimed.

7. A FUEL PRESSURE warning light illuminates indicating less than 4 PSIG fuel pressure.

8. The OIL PRESSURE warning light illuminates after N1 speed reaches 10,000 RPM (20%).

9. The OVERSPEED warning light illuminates.

10. An unusual sound or vibration occurs.

11. A fuel or lubrication oil leak is observed.

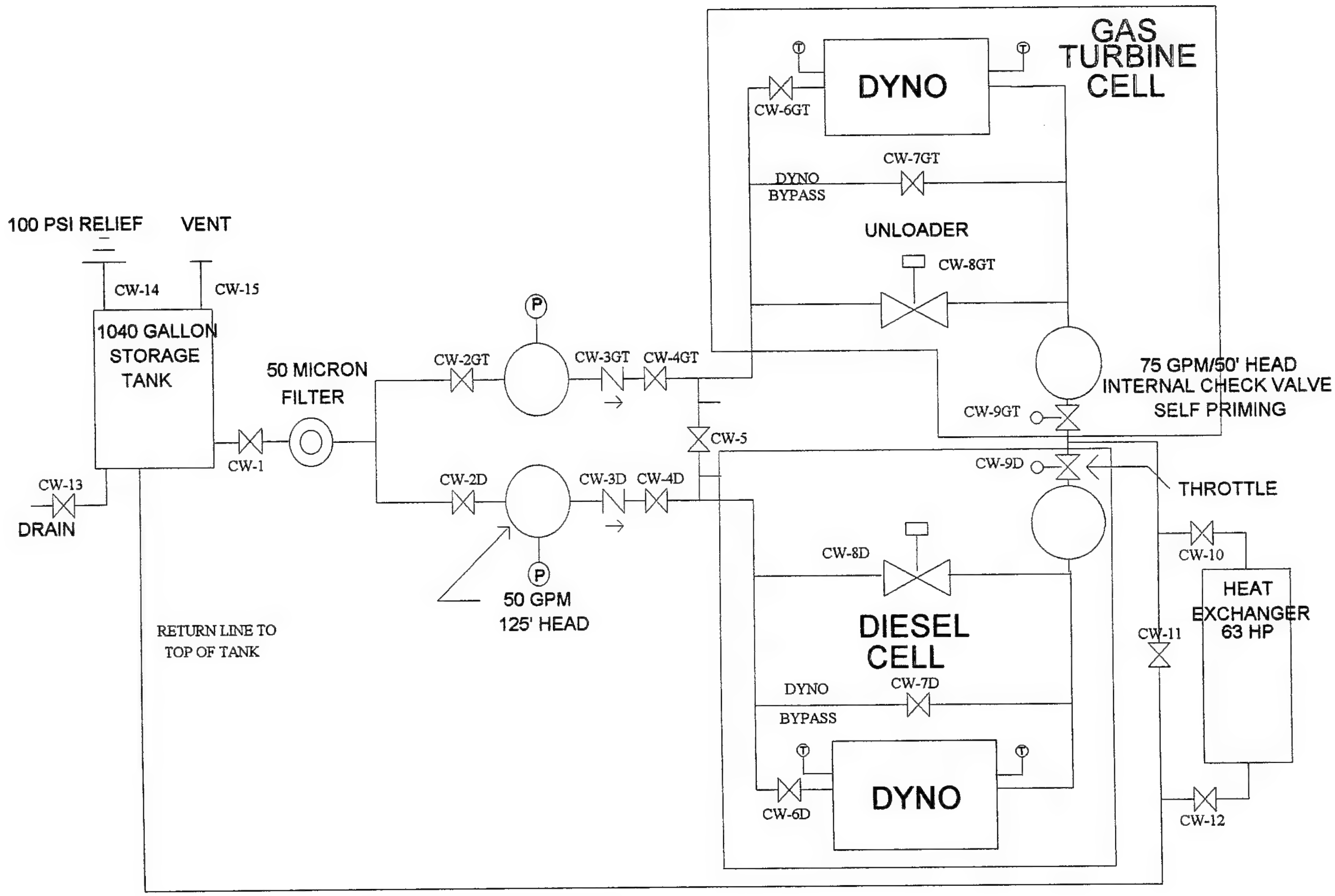


Figure E.1. Dynamometer Water System Schematic

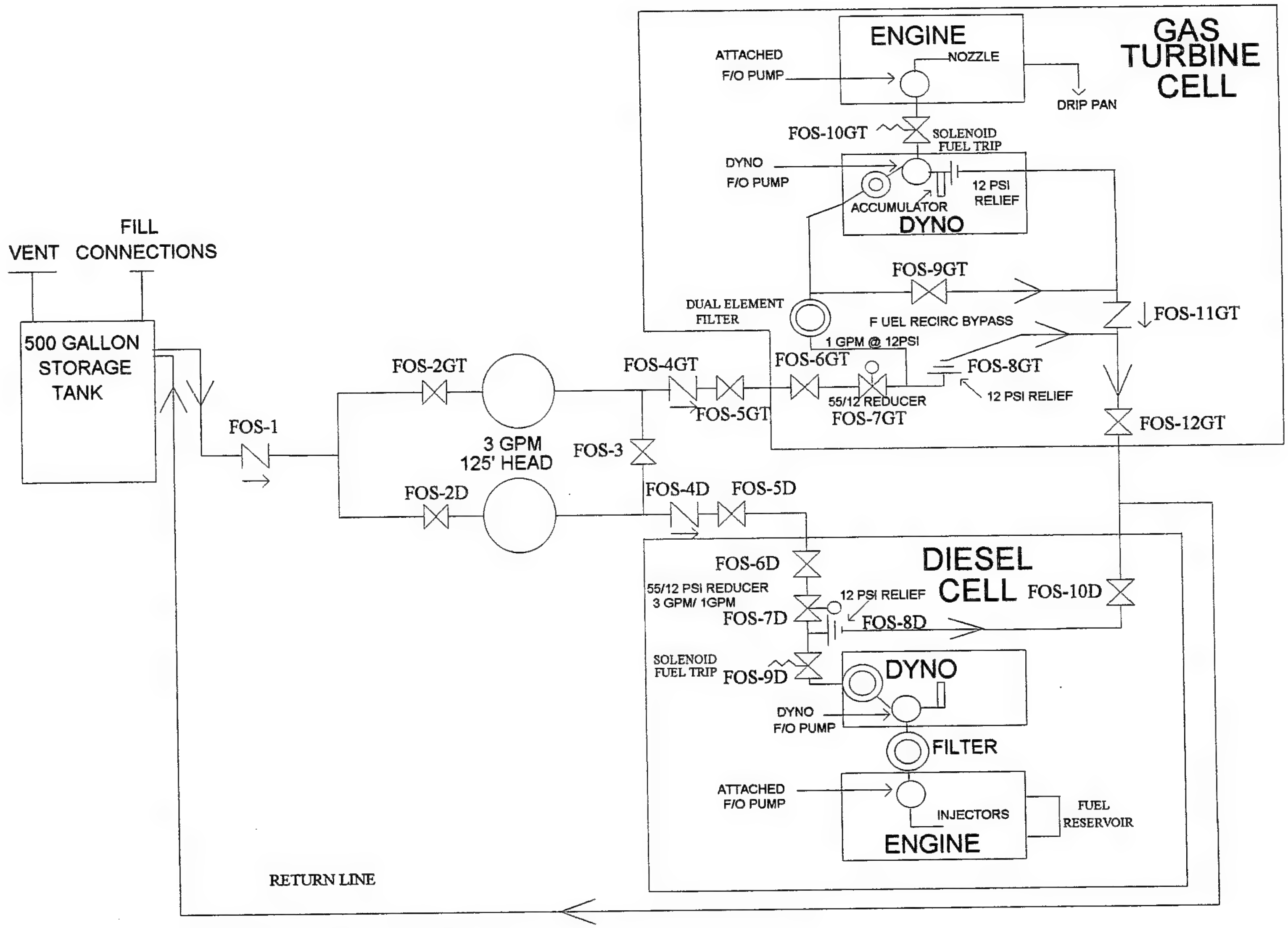


Figure E.2. Fuel System Schematic

FUEL OIL SYSTEM RECIRCULATION PROCEDURE (FOSRP)

PROCEDURE

SYSTEM ALIGNMENT FOR RECIRCULATION

1. Conduct visual inspection of gas turbine test cell and verify the following:

   a. Ensure all drip pans, piping trenches, and the deck are free of oil, fuel, or any flammable liquids.

   b. Ensure all flammable liquids are stored properly in the flammable liquids locker.

   c. Verify that the gas turbine test cell and work area fire extinguishers are fully charged.

   d. Inspect all piping runs and accessories for loose connections, damage, or leaks.

   e. Ensure all valve handwheels are installed and valve labels are in place.

   f. Check fuel level in fuel oil storage tank. Ensure enough fuel is present to support gas turbine operations.

   g. Ensure the intake shutters are closed.

   h. Ensure that the battery charger is disconnected.

2. Ensure the following valves are in the fully open position:

a. Fuel oil supply pump suction valve	FOS-2GT
b. Fuel oil supply pump discharge valve	FOS-5GT
c. Fuel oil supply cell isolation valve	FOS-6GT
d. Fuel oil recirculation valve	FOS-9GT
f. Fuel oil return valve	FOS-12GT

3. Ensure the fuel oil service flow regulator is adjusted between 6-10 PSIG.

4. Ensure the following valves are in the fully closed position:

a. Diesel fuel oil supply pump suction valve	FOS-2D

b. Fuel oil supply cross-connect valve FOS-3

c. Diesel fuel oil return valve FOS-10D

5. Place the local fuel oil supply pump breaker [   ] in the AUTO position.

6. Turn the remote fuel oil pump breaker [   ] to the ON position.

7. Monitor system for possible leaks.

NOTE: The system will recirculate and filter fuel at a rate of 60 gallons per hour. The total storage tank capacity is 500 gallons.

COOLING WATER SYSTEM RECIRCULATION PROCEDURE (CWSRP)

PROCEDURE

<u>SYSTEM ALIGNMENT FOR RECIRCULATION</u>

1. Conduct visual inspection of gas turbine test cell and verify the following:

   a. Inspect all piping runs and accessories for loose connections, damage, or leaks.

   b. Ensure all valve hand wheels are installed and valve labels are in place.

   c. Verify that the water storage tank is full.

   d. Ensure the cooling water system filter is clean and free of excessive particulate.

2. Ensure the following valves are in the fully open position:

a. Water storage tank suction valve	CW-1
b. Water supply pump suction valve	CW-2GT
c. Water supply pump discharge valve	CW-4GT
d. Dynamometer bypass valve	CW-7GT
e. Heat exchanger bypass valve	CW-11

3. Ensure the following valves are in the fully closed position:

a. Diesel supply pump suction valve	CW-2D
b. Gas turbine to diesel cross connect valve	CW-5
c. Dynamometer sump tank supply valve	CW-6GT
d. Diesel return pump discharge valve	CW-9D
e. Return pump discharge valve	CW-9GT
f. Heat exchanger inlet valve	CW-10
g. Heat exchanger discharge valve	CW-12

4. Place the local cooling water supply pump breaker [ ] in the AUTO position.

5. Monitor system and check for leaks.

   NOTE: The water will recirculate at 50 gallons per minute. A full tank will recirculate once every 20 minutes. It is recommended that the system be placed into recirculation mode for a minimum of 40 minutes if the system has been idle more than 30 days.

MASTER NORMAL SHUTDOWN PROCEDURE (MNSP)

PROCEDURE

NORMAL ENGINE AND DYNAMOMETER SHUTDOWN PROCEDURES

1. Return the gas generator control lever (N1) to the IDLE position 30,000-32,000 RPM (60%).

2. Adjust the manual LOAD CONTROL knob to read 8 volts on the TEMPERATURE VOLT meter scale.

3. Allow the engine to run at idle for two minutes to facilitate a sufficient engine cool down.

4. Return the gas generator throttle control to the 0° (cut-off) position.

5. Turn dynamometer FUEL PUMP OFF and monitor for decrease in N1 speed and turbine outlet temperature (TOT).

***NOTE*:** If N1 speed fails to decrease, secure remote fuel oil pump breaker [   ] and monitor N1 speed.

If TOT temperature does <u>NOT</u> decrease and N1 speed does decrease, a post shutdown fire exists. Depress STARTER push-button and motor engine for two minutes.

5. Turn the remote fuel oil supply pump breaker [   ] to the OFF position.

6. Turn the remote cooling water supply pump breaker [   ] to the OFF position.

7. Turn the remote cooling water return pump breaker [   ] to the OFF position.

8. Turn the remote heat exchanger breaker [   ] to the OFF position.

9. Return all local power panel breakers to the OFF position.

10. Depress the POWER ON push-button to de energize the dynamometer control console.

11. Turn off the oil cooler cooling fan.

12. Close the following valves:

a. Fuel oil supply suction valve	FOS-2GT
b. Fuel oil supply pump discharge valve	FOS-5GT
c. Fuel oil return valve	FOS-12GT
d. Water storage tank suction valve	CW-1
e. Water supply pump suction valve	CW-2GT
f. Return pump discharge valve	CW-9GT

13. Ensure all protective covers and plugs are repositioned on all vents and drains.

14. Turn the remote shutter motor breaker [   ] to the OFF position. Ensure that the intake shutters move to the closed position.

15. Turn off the installed cell cooling fans from the wall mounted thermostat when the cell is sufficiently ventilated.

EMERGENCY SHUTDOWN PROCEDURE (ESP)

IMMEDIATE AND CONTROLLING ACTIONS FOR EMERGENCY SHUTDOWN OF THE GAS TURBINE TEST CELL.

***NOTE*:** Emergency shutdown of the T63-A-700 gas turbine engine and dynamometer is directed for any one or combinations of the following casualties:

a. A WATER SUPPLY warning light illuminates which indicates a supply water pressure of less than 15 PSIG is available to the power absorber.

b. A DYNO PRIME warning light illuminates indicating that the power absorber has lost prime.

c. A FUEL PRESSURE warning light illuminates indicating that there is less than 4 PSIG fuel pressure.

d. A fuel oil leak occurs.

e. A WATER TEMP. warning light illuminates indicating a power absorber cooling water discharge temperature of over 210 °F. A normal shutdown should be initiated IAW EOP MNSP if a cooling water discharge of 160 °F or above is observed.

f. An oil pressure of less than 90 PSIG is observed, an automatic shutdown should occur if an oil pressure less than 50 PSIG occurs.

g. An oil leak occurs.

h. An unusual metallic or vibrational sound occurs.

i. The overspeed warning light is illuminated.

j. A fire of any type or severity is observed.

k. A gas generator overspeed of 53,164 RPM (104%) is observed.

l. A power turbine overspeed of 36,400 RPM (104%) is observed.

m. A compressor stall is observed.

n. Erratic control console readings occur.

o. Uncontrolled dyno load fluctuations occur.

p. A turbine outlet temperature (TOT) of 1,380 °F for more than 10 seconds occurs.

q. A TOT of 1,700 °F occurs.

r. An oil temperature of 225 °F or above is observed.

PROCEDURE

1. Turn the dynamometer FUEL PUMP OFF and return the gas generator throttle control to the 0° (cut-off) position. Monitor for a decrease in N1 speed and TOT temperature.

NOTE: If N1 speed fails to decrease, secure remote fuel oil pump breaker [ ] and monitor N1 speed.

If TOT temperature does NOT decrease and N1 speed does decrease, a post shutdown fire exists. Depress STARTER push-button and motor engine for two minutes.

2. After N1 speed reaches 0 RPM (0%) proceed with normal shutdown IAW SOP MNSP.

NOTE: In the event of a fire, call the fire department at extension X2333.

Attempt to put out fire with CO_2 extinguisher only after calling fire department.

3. Troubleshoot and investigate malfunction prior to attempting a restart of the engine.

LIST OF REFERENCES

1. Allison Gas Turbines, *Model-C18 Installation Design Manual,* 1976

2. Department of the United States Army, *Aviation Unit and Aviaition Intermediate Maintenance Manual*, TM 55-2840-231-23, 1982

3. Point of Contact Thomas F. Piercy, Chief Test Engineer, Allison Engine CO - Mail Code 515 Indianapolis, IN 46206, PH: (317) 230-5406, May 1995

4. Point of Contact Rod Gwillam, Executive V.P., Turbomotive Inc., 285 Welton Street, Hamden CT 06517, PH (203) 789-0243, June 1995

5. Superflow Corporation, *SF-901 Instruction Manual*, 1993

6. Point of Contact Mike Girdley, Allison 250 Customer Service Representative, Allison Engine CO - Mail Code P40A Indianapolis, IN 46206 PH: (317) 230-2718

7. Point of Contact Tom Paullins, Superflow Corp. Customer Service Representative 3512 N. Tejon, Colorado Springs, CO 80907 PH: (719) 471-1746

8. Point of Contact Leslie Jordan, Customer Service Representative California-AmericanWater Company of Monterey CA, PH (408) 375-8845 Jan 1995

9. Streeter, V.L.and Wylie,E. B. *"Fluid Mechanics"* 8th edition, McGraw Hill, 1985

10. Department of the United States Army, *Aviation Maintenance Repair Parts and Special Tools List and Technical Manual*, TM 55-1520-228-23P, 1982

11. Point of Contact Rey Schmidt, Engineered Products Divisiion, C.H. Bull CO., 233 Utah Avenue, South San Francisco CA, 94080 PH: (415) 871-8448, Quotation 5228-S May 1995

12. Department of the United States Army, *Operator's Manual Army Model OH-58A/C Helicopter,* TM 55-1520-228-10, 1982

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